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CALCULATIONS PERTAINING TO THE ENERGY
BALANCE AND PLASMA MOTIONS IN THE
IONOSPHERE

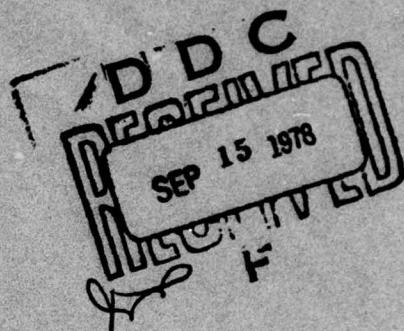
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AD A0 58684

June 1978

Final Report
1 October 1976 - 31 December 1977



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19 REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM	
18. REPORT NUMBER AFGL TR-78-0153	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER	
6. TITLE Calculations Pertaining to the Energy Balance and Plasma Motions in the Ionosphere.		5. TYPE OF REPORT & PERIOD COVERED Final Report 1 Oct 76 - 31 Dec 77	
10. AUTHOR Alex Dalgarno Eustratios/Constantinides		8. CONTRACT OR GRANT NUMBER(S) F19628-77C-0030	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Smithsonian Astrophysical Observatory 60 Garden St. Cambridge, MA 02138		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 2311G2AD	
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory Hanscom AFB, Massachusetts 01731 Monitor/Rita C. Sagalyn/FHR		12. MONTH AND YEAR Jun 78	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified	
16. DISTRIBUTION STATEMENT (of this Report) A - Approved for public release; distribution unlimited		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE 12 48p.	
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)			
18. SUPPLEMENTARY NOTES			
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Ionospheres Electric Fields Transport Properties			
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Under the present contract, a research effort was undertaken to develop theoretical and computational techniques pertaining to the energy balance and plasma motions in the ionosphere. Emphasis has been placed on the utilization of available satellite data as input to the calculations and as a test of the validity of the theoretical methods. The effect of ambipolar diffusion on the concentration profile has been investigated. Calculations show that diffusive transport produces qualitative agreement between observed and calculated profiles. Additional			

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applications are required to produce definitive results.

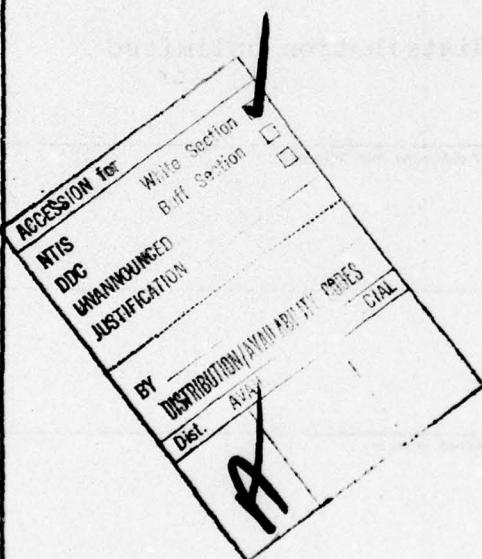
Procedures for the calculation of the rate of energy deposition by solar EUV flux and of the rate of photoionization of the principal atmospheric constituents have been revised. The associated computer codes have been modified or rewritten. The atomic and molecular cross sections utilized by these codes have been updated. The total photoionization cross section of atomic oxygen was revised significantly. Branching ratios for the photoionization of N_2 and O_2 are substantially different from those used previously.

Future work undertaken under contract F19628-78-C-0047 will incorporate electric fields into the transport equations. The study of the spectrum of secondary electrons produced by energetic precipitating particles will be continued under the new contract.

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SECTION I

INTRODUCTION AND SUMMARY

Knowledge of the energy balance and plasma motions in the ionosphere is essential for the accurate prediction of atmospheric effects on radio communications under both normal and disturbed conditions. The major source of energy in the upper atmosphere is the extreme ultraviolet (EUV) solar flux. In addition, the EUV flux is the major source of ionization in the daytime at midlatitudes. At high latitudes, precipitating energetic particles contribute substantially to and at times dominate the energy budget and rate of ionization of the topside ionosphere. Charged particle motions, due primarily to diffusion, electric fields, and neutral winds, play a major role in determining local ion concentrations as well as the rate of energy transport.

A major part of the effort under the present contract was devoted to developing procedures and computer codes for the calculation of the diffusive transport of atomic oxygen ions. The pertinent equations are given in Appendix B, and the results are discussed in Section II. In general the calculations show that diffusive transport produces qualitative agreement between the observed and calculated profiles of atomic oxygen ions.

Procedures for the calculation of the rate of energy deposition by solar EUV flux and of the rate of photoionization of the principal

atmospheric constituents have been revised, and the associated computer codes have been modified or rewritten. The necessary atomic and molecular data have been updated and are given in detail in Appendix A.

SECTION II

DIFFUSIVE TRANSPORT OF ATOMIC OXYGEN IONS

A part of the current study pertains to the study of plasma motions in the ionosphere. The agents of ionospheric transport are ambipolar diffusion, electric fields, neutral winds, and to some extent temperature gradients of the ionized components.

For the principal molecular ions, O_2^+ , N_2^+ , and NO^+ , transport processes are unimportant in the daytime. The short chemical reaction times of these ions cause them to be in photochemical equilibrium at all altitudes. This has been demonstrated in a theoretical study by Schunk and Walker (1973), and by a comparison of calculated and observed molecular ion profiles by Oppenheimer et al. (1977).

A typical comparison is shown in Figure 1. The principal molecular ions are also insensitive to transport processes in the nighttime ionosphere above about 200 kilometers (cf. Schunk and Walker, 1973). Below this altitude, the time scales associated with transport due to neutral winds and electric fields are comparable to photochemical times, and photochemical equilibrium no longer prevails.

In contrast to the molecular ions, O^+ ceases to be in photochemical equilibrium at altitudes above the F_2 peak (~ 250 km) even in daytime. The departure from photochemical equilibrium is clearly demonstrated by Figure 2. This departure is thought to be primarily due to the effects of ambipolar diffusion. Accordingly an effort

was undertaken to study these effects in situations where both the neutral and ionized ionospheric constituents are known.

The formulation of the equations for diffusive transport is outlined in Appendix B. Since the electric field is not among the observed quantities, the current formulation eliminates it from the transport equations. In future work, a modified version will study the effects of sample electric fields compatible with those observed by AFGL satellite measurements.

Since the diffusion equation is of second order, two boundary conditions are required for a solution. One of the boundary conditions is chosen to be the O^+ concentration of the lower boundary (200 km in the present calculations). For the second boundary condition two different choices were made. One was to fix the O^+ concentration at some upper boundary (chosen as 470 km in the present calculations), or to fix the O^+ flux at some upper boundary (chosen as 600 km in the present calculations). Figure 3 displays the results of two calculations with fixed concentrations at the upper boundary. Figure 4 displays the results of three calculations with fixed flux at the upper boundary. In both figures the observed O^+ concentration has been plotted as well (in this instance data from orbit 594 of the AE-C satellite were used). For either type of upper boundary condition the altitude profiles are in marked contrast to the profile calculated under the assumption of local photochemical equilibrium. The latter calculation results in a profile which increases exponentially above the F_2 peak. Calculations

including diffusion, on the other hand, result in profiles that qualitatively reproduce the observed decline of the concentration above the F_2 peak. The results obtained with fixed upper boundary concentration (Figure 3) are generally less satisfactory in the sense that a reasonable O^+ value at the top of the atmosphere forces very large values at the F_2 peak. The calculations with fixed-flux upper boundary condition are in better qualitative agreement with the observed profile (for the case where the flux is set to zero).

Ideally, a truly vertical O^+ concentration profile is needed for comparison with the calculations. In the absence of such data, however, the closest available approximation to a vertical profile is data from a highly elliptic satellite orbit. Even for such orbits, however, the satellite observations reflect horizontal variations, where such variations exist. The search for orbits which are known to be free from horizontal variations, and which, at the same time, contain all the necessary data has so far been unsuccessful. Diffusive transport calculations for other orbits will, however, serve as a criterion of whether the adopted procedures are valid.

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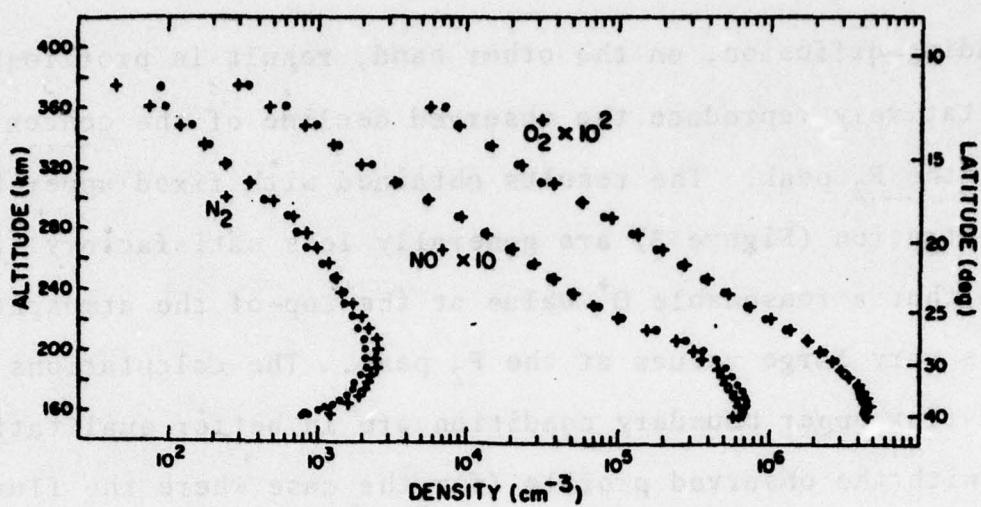


Fig. 1. The densities of the molecular ions plotted against altitude and latitude. Dots indicate measurements by the MIMS experiment for the upleg of orbit 594 of the AE-C satellite. Pluses indicate theoretical values (Oppenheimer et al., 1977).

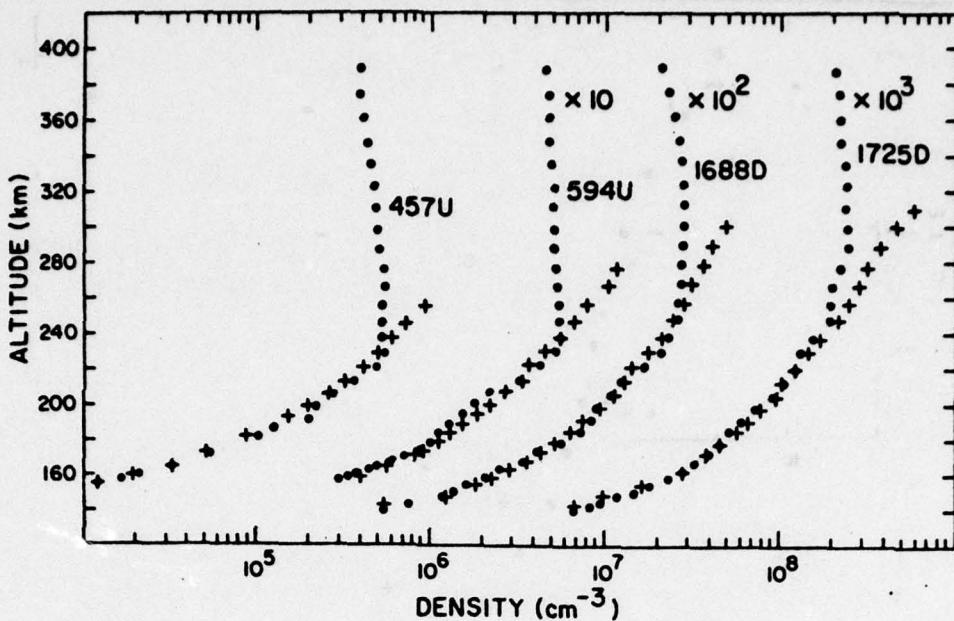


Fig. 2. The density of O^+ plotted against altitude. Dots indicate measurements by the MIMS experiment for four orbits of the AE-C satellite. Pluses indicate theoretical values calculated on the assumption of local photochemical equilibrium (Oppenheimer et al., 1977). The divergence of the theoretical and measured profiles above the F_2 peak demonstrates the breakdown of local photochemical equilibrium.

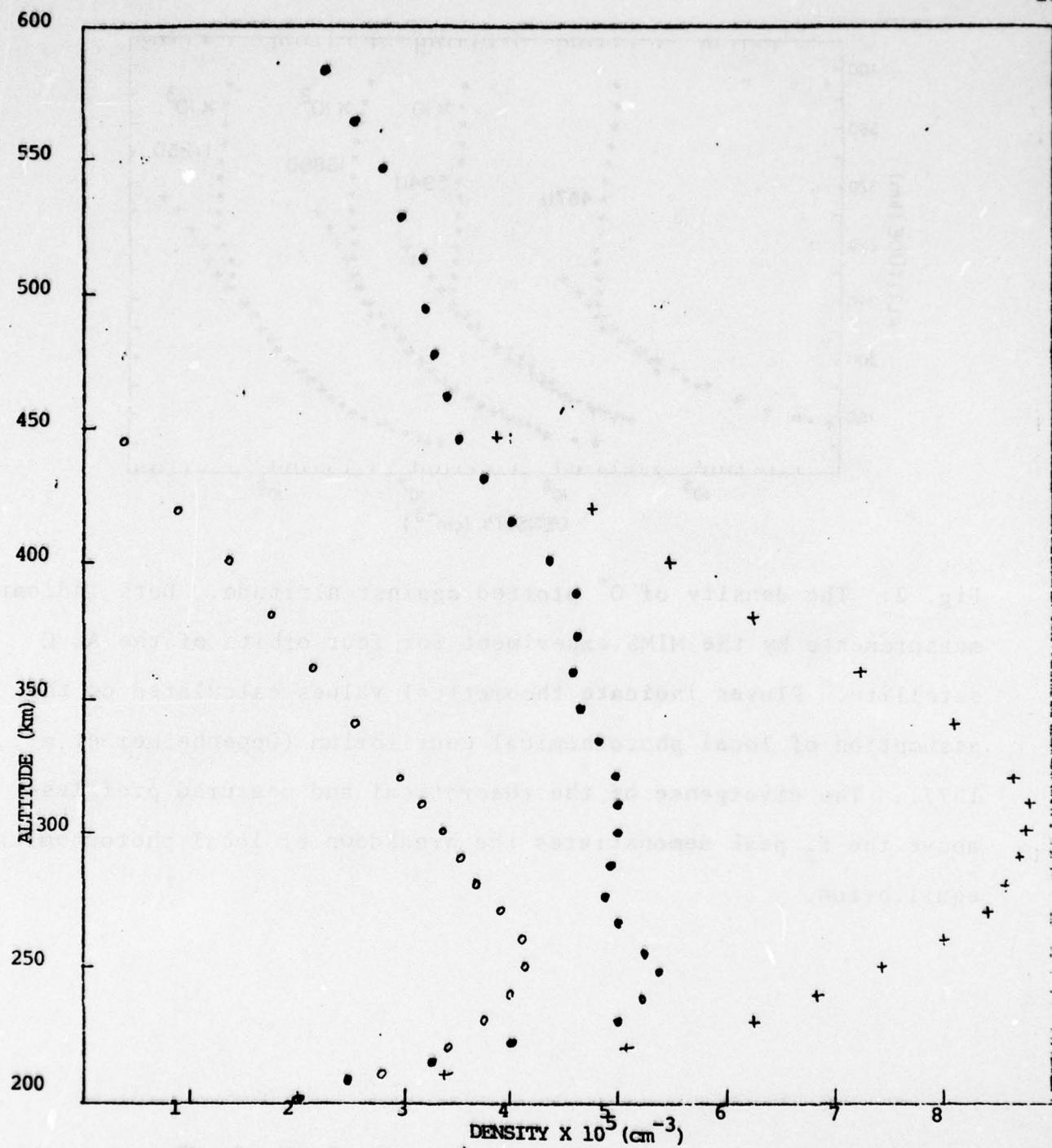


Fig. 3. The density of O^+ plotted against altitude. Filled circles indicate measurements by the BIMS experiment for orbit 594, upleg, of the AE-C satellite. Also shown, as open circles and pulses, are the results of two calculations based on a "fixed density" boundary condition at 470 km.

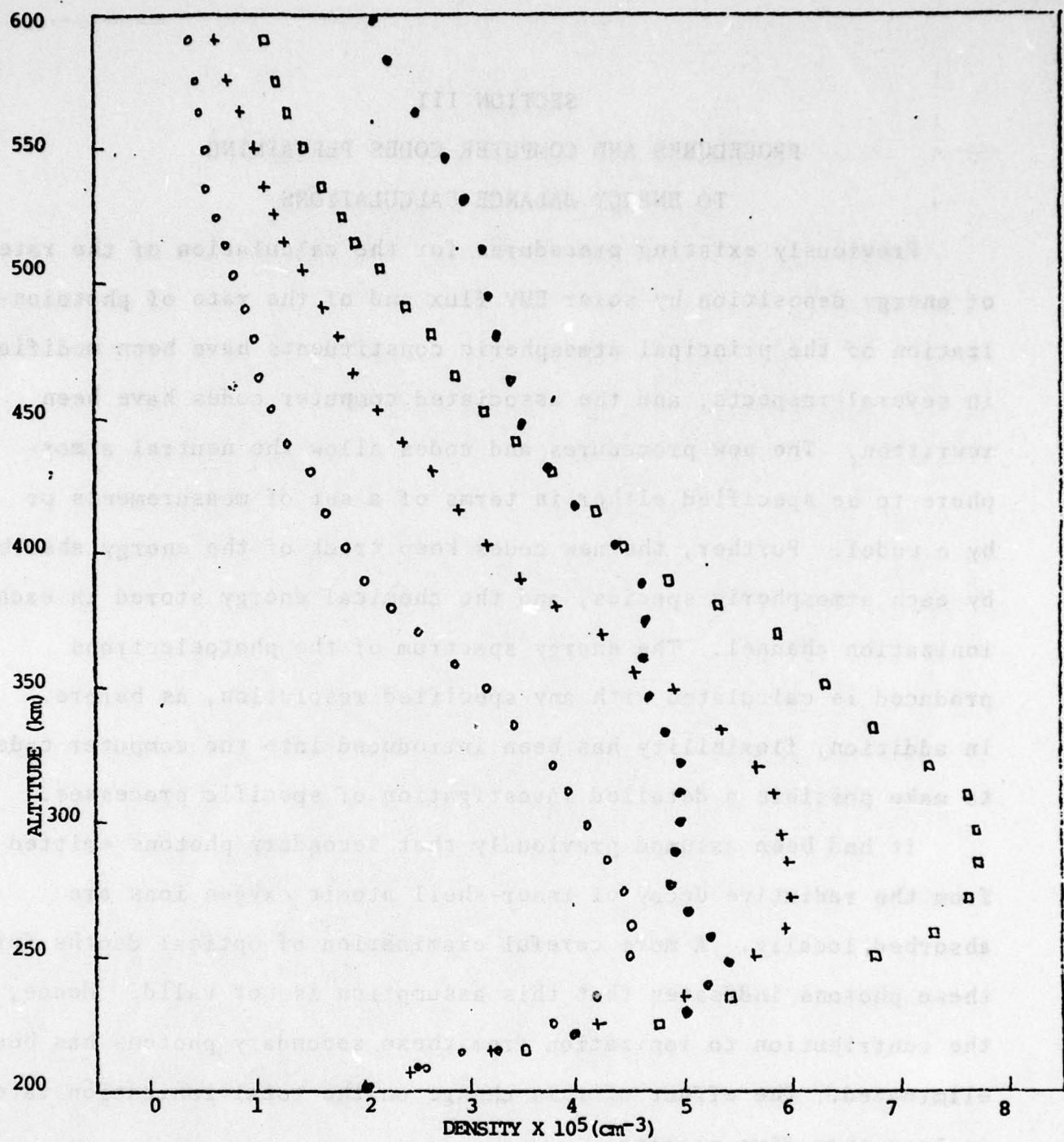


Fig. 4. The density of O^+ plotted against altitude. Filled circles indicate measurements by the BIMS experiment for orbit 594, upleg, of the AE-C satellite. Also shown are the results of three calculations based on a fixed flux boundary condition at 600 km: $000 \phi = 5 \times 10^8$, $+++ \phi = 0$, $\square \square \square \phi = 5 \times 10^8$. Flux is in units of $\text{cm}^{-2} \text{ sec}^{-1}$.

SECTION III

PROCEDURES AND COMPUTER CODES PERTAINING TO ENERGY BALANCE CALCULATIONS

Previously existing procedures for the calculation of the rate of energy deposition by solar EUV flux and of the rate of photoionization of the principal atmospheric constituents have been modified in several respects, and the associated computer codes have been rewritten. The new procedures and codes allow the neutral atmosphere to be specified either in terms of a set of measurements or by a model. Further, the new codes keep track of the energy absorbed by each atmospheric species, and the chemical energy stored in each ionization channel. The energy spectrum of the photoelectrons produced is calculated with any specified resolution, as before. In addition, flexibility has been introduced into the computer codes to make possible a detailed investigation of specific processes.

It had been assumed previously that secondary photons emitted from the radiative decay of inner-shell atomic oxygen ions are absorbed locally. A more careful examination of optical depths for these photons indicates that this assumption is not valid. Hence, the contribution to ionization from these secondary photons has been eliminated. The effect of this change on the total ionization rate is less than five percent.

The atomic and molecular cross sections utilized by those codes have been revised significantly. A detailed description of the cross sections currently in use is given in Appendix A.

The code that calculates the equilibrium electron flux has been modified to some extent in order to make it suitable for execution on a CDC system. A listing and a punched-card copy of this code, together with the necessary input files, is being submitted separately. A sample execution on a CDC-6400 system is also being submitted.

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APPENDIX A

Atomic and Molecular Cross Sections

The extreme ultraviolet (EUV) solar flux supplies the major energy input in the upper atmosphere. In addition, the EUV flux is the major source of ionization in the daytime at midlatitudes. To account properly for the rates of energy deposition and ionization in the upper atmosphere accurate photoabsorption and photoionization cross sections are required. This appendix contains cross sections for the most important atmospheric constituents. These cross sections are based on critical reviews and evaluations of laboratory and theoretical data. A considerable body of new data has become available recently. The agreement among results reported by various investigators is good (generally within 10% or better). Consequently the present body of cross section data may be considered complete insofar as aeronomic calculations are concerned, at least at wavelengths longer than 300 \AA .

A.1 Atomic Oxygen Cross Sections

The photoionization of atomic oxygen through the removal of the 2p valence shell electron leads to $\text{O}^+(^4\text{S}^0)$, $\text{O}^+(^2\text{D}^0)$, and $\text{O}^+(^2\text{P}^0)$ with thresholds at 910.4 \AA , 732 \AA , and 665 \AA respectively. The partial cross sections for these processes as calculated by Henry (1970) have been renormalized using

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the total ionization cross section calculated by Taylor and Burke (1976). Ionization through the removal of a 2s inner shell electron gives rise to $O^+(^4P^e)$ and $O^+(^2P^e)$ with thresholds at 435 \AA and 315 \AA respectively. The partial cross sections for these processes were obtained from a calculation by Dalgarno, Henry and Stewart (1964) as modified by Henry (1967). The total ionization cross sections at wavelengths shorter than 435 \AA were obtained by adding the partial cross sections for inner shell ionization to the total ionization cross sections of Taylor and Burke.

Table A-1 displays the total and partial ionization cross sections at selected wavelengths between 14.25 \AA and 910 \AA . Cross sections at other wavelengths can be obtained by linear interpolation.

A. 2 Molecular Oxygen Cross Sections

Total absorption (and ionization) cross sections in the region 14 \AA - 662 \AA were derived from the data of Lee, Carlson, Judge and Ogawa (1973), Samson, Gardner and Haddad (1977), Mehlman, Ederer and Saloman (1978), and Huffman (1963).

In the region 662 \AA - 870 \AA a least squares fit to the values of Cook and Metzger (1964) was used. The 870 \AA - 1030 \AA region is marked by wider, well separated peaks. Using data from Huffman (1963) a background cross section σ_b was obtained by drawing in a baseline, upon which the peak

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cross section σ_p was superimposed. Each peak area was approximated as a square wave over the same wavelength interval as the actual triangular line shape. Total absorption and total ionization cross sections are displayed in Tables A-2 and A-3 respectively.

Branching ratios as a function of wavelength were assigned on the basis of the results of Samson, Gardner and Haddad (1977), and of Fryar and Browning (1973). Samson et al. detected nine photoionization channels, of which the last five are predissociating states. Fryar and Browning have measured the total cross section for dissociative ionization.

Between the threshold for photoionization at 1026 \AA and the threshold for dissociative ionization at 662 \AA , we have used the branching ratios of Samson et al. with the following exception: Samson et al. give combined values for the $a^4\Pi_u$ and $A^2\Pi_u$ states. We have assigned the (small) branching ratios for the $A^2\Pi_u$ state on the basis of earlier work by Schoen (1969), and thus derived branching ratios for the $a^4\Pi_u$ state from the combined values of Samson et al.

In the region between 303 \AA and 662 \AA , the total cross section for dissociative ionization of Fryar and Browning (1973) exceeds the sum of the partial cross sections for the predissociating states observed by Samson et al. To reconcile this difference we have postulated the existence

of a single additional predissociating branch with threshold at 662 Å. A straightforward algorithm yields branching ratios for this (tenth) additional branch as well as renormalized branching ratios for the branches observed by Samson et al.

No measurements of the branching ratios have been reported at wavelengths shorter than 303 Å. We have arbitrarily assumed that branching ratios remain constant short of 303 Å. This assumption is of minor importance for most aeronomic applications.

Table A-4 displays branching ratios at selected wavelengths between 14 Å and 1026 Å for each of ten branches. At other wavelengths the branching ratios can be obtained by linear interpolation. It should be kept in mind that the last six branches represent dissociative ionization.

Branching Ratios for the Photoionization of O_2

Branch	1	2	3	4	5	6	7	8	9	10
Designation	$x^2 \Pi_g$	$a^4 \Pi_u$	$A^2 \Pi_u$	$b^4 \Sigma_g^-$	$B^2 \Sigma_g^-$	$2 \Pi_u$	$c^4 \Sigma_u^-$	$2 \Sigma_u^-$	$2,4 \Sigma_g^-$	662 \AA
$\lambda (\text{\AA})$	Branching Ratios									
14	0.365	0.185	0.020	0.125	0.055	0.060	0.035	0.030	0.125	0.000
303	0.365	0.185		0.125				0.030	0.125	0.000
323								0.000	0.000	0.112
454										0.055
461	0.435	0.225		0.120	0.055	0.060	0.035			0.050
504								0.000		0.115
537	0.345	0.270		0.130						0.137
556		0.210		0.225						
573	0.365	0.250								0.030
584		0.310								0.030
598	0.30	0.275								0.045
610		0.365						0.305	0.000	0.075
637	0.245	0.330						0.370		
645	0.340	0.285						0.330		
662	0.270							0.345		
684		0.468						0.000		
704	0.675	0.275								
720	0.565	0.385								
737	0.565	0.435								
774	1.000	0.000								
1026	1.000									

A.3 Molecular Nitrogen Cross Sections

Total absorption (and ionization) cross sections in the region $100 \text{ \AA} - 650 \text{ \AA}$ were derived from the data of Lee, Carlson, Judge and Ogawa (1973) and of Samson, Haddad and Gardner (1977). The data were extrapolated from 100 \AA to 14 \AA° so that consistency was obtained with the cross section measurements by Huffman (1969) at 100 \AA° , 68 \AA° , 44.6 \AA° and 13.4 \AA° . From 650 \AA° to 734 \AA° total absorption cross sections were obtained from Huffman (1969) by superimposing peak values on a baseline representing the continuum, as for molecular oxygen. From 734 \AA° to 986 \AA° cross sections were derived from the tabulated oscillator strengths of Carter (1972). Ionization yields from 650 \AA° to the photoionization threshold at 796 \AA° were obtained by a least squares fit to the data of Cook and Metzger (1964). Above 1000 \AA° no detectable absorption was observed by Huffman, Tanaka and Larrabee (1963). Thus from 986 \AA° to 1030 \AA° the absorption cross section has been set to zero. Total absorption and total ionization cross sections are displayed in Tables A-5 and A-6 respectively.

Dissociative ionization of N_2 is assumed to occur through a single channel with threshold at 509 \AA° . The partial cross section for dissociative ionization is obtained by multiplying the total ionization cross section by the fractional yield for dissociative ionization. The remaining part of the total ionization cross section is apportioned among five branches of N_2^+ . Fractional yields for dissociative ionization are displayed in Table A-7 for wavelengths

51

68

or

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between 14°A and 509°A . At other wavelengths the yield can be obtained by linear interpolation, with one exception: between 387°A and 477°A the yield, Y , is given by

$$Y = 0.0329 + 8.13 \times 10^{-6} \times (\lambda - 442)^2$$

Values for the yield for dissociative ionization were derived from the data of Wight, Van der Wiel and Brion (1976), and of Fryar and Browning (1973).

Branching ratios as a function of wavelength for five N_2^+ branches were derived from the data of Samson, Haddad and Gardner (1977), Plummer, Gustafson, Gudat and Eastman (1977), Hamnet, Stoll and Brion (1976), and Lee (1977). The agreement among the results published by these investigators is good (generally within 10%). No measurements have been reported at wavelengths shorter than 210°A . We have arbitrarily assumed that branching ratios remain constant short of 210°A . This assumption is of minor importance for most aeronomic calculations. Table A-8 displays branching ratios between 14°A and 795°A for each of five branches. At other wavelengths the branching ratios can be obtained by linear interpolation.

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Table A-7

Fractional Yield for Dissociative Ionization of N_2

<u>λ (A)</u>	<u>Yield</u>
14	0.360
210	0.360
240	0.346
302	0.202
387*	0.033
477*	0.041
496	0.024
509	0.000

*See text

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Table A-8

Branching Ratios for the Photoionization of N_2

Branch	1	2	3	4	5
Designation	$X^2\Sigma_g^+$	$A^2\Pi_u$	$B^2\Sigma_u^+$	$F^2\Sigma_u$	$^2\Sigma_g^+$
λ (Å)					Branching Ratios
14	0.271	0.275	0.110	0.064	0.278
210		0.275			0.278
240		0.345	0.110	0.064	0.210
280		0.470	0.095	0.040	0.124
300	0.271	0.470	0.110	0.074	0.075
332	0.300	0.520	0.120	0.060	0.000
428	0.460	0.460	0.080	0.000	
500	0.404	0.506	0.090		
600	0.308	0.589	0.103		
660	0.308	0.589	0.103		
660.01		0.692	0.000		
720	0.420	0.580			
747	1.000	0.000			
795	1.000				

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A.4 Helium Cross Sections

For helium, with a photoionization threshold at 504 Å, we have used the cross sections given by Jacobs (1971). These are displayed in Table A-9.

TABLE A-1
TOTAL AND PARTIAL PHOTOIONIZATION CROSS SECTIONS
FOR ATOMIC OXYGEN (IN MEGABARNS)

λ (Å)	Total	$4S^0$	$2D^0$	$2P^0$	$4P^e$	$2P^e$
14.25	0.322	0.095	0.102	0.063	0.031	0.025
30.02	0.277	0.087	0.098	0.058	0.027	0.021
46.40	0.261	0.078	0.083	0.055	0.025	0.020
50.30	0.423	0.123	0.140	0.089	0.040	0.032
75.03	0.824	0.245	0.253	0.173	0.079	0.063
90.14	1.527	0.455	0.466	0.321	0.147	0.117
105.23	2.310	0.685	0.736	0.496	0.222	0.176
127.65	3.714	1.108	1.194	0.782	0.357	0.284
150.10	4.789	1.372	1.562	1.025	0.460	0.370
180.40	5.920	1.611	1.931	1.293	0.571	0.465
200.00	5.633	1.759	2.253	1.465	0.651	0.510
220.08	7.345	1.905	2.531	1.640	0.725	0.544
243.03	9.087	2.064	2.844	1.836	0.763	0.561
256.37	9.432	2.154	3.023	1.947	0.818	0.556
270.50	8.906	2.245	3.210	2.061	0.858	0.532
284.15	9.262	2.332	3.387	2.168	0.969	0.487
303.78	9.719	2.451	3.535	2.316	0.914	0.405
315.02	9.573	2.507	3.755	2.392	0.923	0.000
335.39	10.127	2.636	4.014	2.540	0.938	
349.95	10.456	2.713	4.173	2.631	0.940	
368.07	10.837	2.811	4.371	2.743	0.915	
401.70	11.265	2.930	4.529	2.873	0.835	
413.00	11.435	2.935	4.740	2.925	0.785	
435.00	11.609	3.049	4.959	2.981	0.720	
456.00	10.500	3.052	4.964	2.984	0.000	
459.00	11.100	3.109	4.967	3.025		
454.00	11.307	3.167	5.060	3.081		
455.00	11.855	3.331	5.234	3.240		
456.00	11.765	3.295	5.265	3.204		
457.00	11.603	3.252	5.196	3.150		
458.00	11.503	3.222	5.150	3.131		
459.00	11.425	3.201	5.116	3.108		
460.00	11.373	3.186	5.092	3.093		
462.00	11.320	3.177	5.071	3.077		
464.00	11.263	3.159	5.049	3.051		
466.00	11.242	3.132	5.038	3.052		
467.00	11.165	3.131	5.005	3.031		
468.00	11.077	3.106	4.945	3.006		
470.00	11.000	3.035	4.832	2.987		
471.00	10.917	3.067	4.896	2.959		
472.00	10.783	3.025	4.935	2.922		
473.00	10.553	2.941	4.733	2.859		
474.00	9.991	2.803	4.492	2.706		
475.00	9.012	2.641	4.222	2.543		
476.10	11.447	3.213	5.136	3.096		

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TABLE A-2
MOLECULAR OXYGEN ABSORPTION CROSS SECTIONS σ_T (Mb)

λ	σ_T								
14.25	0.29	14.40	0.29	15.01	0.29	15.26	0.29	16.71	0.29
16.77	0.29	17.05	0.29	17.11	0.29	18.62	0.29	18.97	0.29
21.40	0.29	21.80	0.29	22.10	0.29	28.47	0.30	26.79	0.30
24.54	0.30	25.02	0.30	30.43	0.30	33.74	0.30	40.95	0.31
45.76	0.31	44.02	0.31	44.16	0.31	45.66	0.33	46.40	0.35
45.67	0.36	47.87	0.39	49.22	0.42	50.36	0.45	50.52	0.45
50.69	0.46	52.30	0.50	52.91	0.51	54.15	0.54	54.42	0.55
54.70	0.54	55.06	0.57	55.34	0.57	56.09	0.59	56.92	0.61
57.76	0.62	57.56	0.63	57.88	0.64	58.95	0.66	59.62	0.68
60.30	0.70	60.65	0.71	61.07	0.72	61.53	0.73	61.99	0.74
62.30	0.75	62.35	0.75	62.77	0.76	62.92	0.76	63.15	0.77
63.30	0.77	63.65	0.78	63.72	0.78	64.11	0.79	64.60	0.80
65.71	0.82	65.71	0.83	65.85	0.84	66.30	0.85	67.14	0.87
67.35	0.87	68.35	0.91	59.65	0.95	70.00	0.96	70.54	0.98
70.75	0.93	71.00	0.99	71.54	1.01	72.31	1.02	72.63	1.03
72.80	1.04	72.95	1.04	73.55	1.06	74.21	1.08	74.44	1.08
74.20	1.10	75.02	1.10	75.29	1.11	75.46	1.11	75.73	1.12
75.01	1.13	75.46	1.14	76.83	1.15	76.74	1.15	77.30	1.16
77.74	1.19	78.56	1.20	78.70	1.20	79.78	1.21	79.46	1.23
79.76	1.27	83.00	1.24	30.21	1.25	80.55	1.26	30.94	1.27
81.16	1.27	81.58	1.28	51.94	1.29	82.43	1.31	32.67	1.31
83.25	1.33	33.42	1.34	33.67	1.34	34.70	1.35	34.26	1.36
84.50	1.37	84.72	1.37	94.85	1.38	25.16	1.38	35.50	1.39
85.67	1.40	15.67	1.40	96.23	1.41	86.40	1.42	34.77	1.43
86.98	1.44	57.00	1.44	37.61	1.45	89.10	1.47	96.11	1.47
88.14	1.47	53.42	1.48	95.64	1.48	83.90	1.49	89.14	1.50
89.70	1.51	53.14	1.52	90.45	1.53	90.71	1.54	51.70	1.55
91.48	1.56	51.65	1.57	91.81	1.57	92.09	1.58	92.55	1.59
92.81	1.60	53.61	1.62	94.07	1.63	94.25	1.64	94.35	1.64
94.91	1.65	54.90	1.66	95.67	1.67	95.51	1.67	95.81	1.68
96.05	1.67	53.49	1.70	36.03	1.71	97.12	1.72	97.51	1.73
97.97	1.67	53.12	1.75	32.23	1.75	98.53	1.76	98.83	1.77
99.44	1.73	53.71	1.75	95.59	1.80	100.54	1.84	101.96	1.86
101.57	1.90	102.15	1.94	103.01	2.00	103.15	2.01	102.17	2.01
103.50	2.04	103.94	2.05	104.23	2.08	104.76	2.11	105.23	2.15
106.25	2.21	105.57	2.23	104.93	2.26	108.05	2.33	108.45	2.36
109.50	2.47	109.50	2.45	110.56	2.50	110.52	2.50	110.75	2.51
111.16	2.54	111.25	2.54	113.87	2.71	114.09	2.73	114.24	2.74
112.35	2.82	115.82	2.34	116.75	2.91	117.20	2.94	120.40	3.15
121.15	3.20	121.75	3.24	122.70	3.30	123.50	3.35	127.65	3.62
125.67	3.77	127.35	3.92	131.02	3.96	131.01	3.97	134.21	4.26
131.28	4.27	133.54	4.27	136.45	4.23	136.42	4.23	144.21	4.79
141.00	4.85	140.56	5.05	150.10	5.21	152.15	5.33	152.34	5.33
154.20	5.44	157.70	5.36	158.38	5.70	159.34	5.30	154.13	5.03
167.50	6.32	143.17	6.37	145.55	6.40	168.92	6.42	171.06	6.53
172.12	6.65	172.72	6.71	173.10	6.72	174.57	6.32	175.24	6.87
175.47	6.89	177.22	7.01	178.02	7.03	175.74	7.13	180.43	7.22
186.71	7.24	181.14	7.27	182.16	7.35	182.39	7.34	186.91	7.44
194.10	7.45	174.52	7.47	134.75	7.49	185.21	7.52	136.60	7.60
198.87	7.62	183.23	7.73	158.70	7.72	190.00	7.90	191.29	7.87
199.30	7.93	182.50	7.95	193.50	8.00	155.14	8.05	192.63	8.13

TABLE A-2 (continued)

λ	σ_T								
177.41	8.27	198.53	8.30	200.00	8.40	201.17	8.48	202.64	8.60
203.78	8.67	204.89	8.78	206.26	8.90	206.38	8.91	207.46	9.00
208.36	9.07	209.63	9.17	209.78	9.18	209.93	9.19	211.32	9.30
212.15	9.35	214.75	9.54	215.16	9.57	216.30	9.58	216.21	9.77
219.07	9.87	220.08	9.91	221.26	9.99	221.51	10.01	223.26	10.15
223.72	10.10	224.81	10.27	225.12	10.30	227.01	10.45	227.47	10.49
228.74	10.69	230.65	10.75	231.55	10.83	232.50	10.91	233.84	11.01
234.35	11.05	235.55	11.15	237.36	11.29	239.97	11.49	240.75	11.56
243.03	11.74	245.94	11.97	246.24	12.00	246.71	12.05	247.13	12.07
249.20	12.24	251.10	12.39	251.96	12.46	252.17	12.48	253.80	12.61
256.37	12.82	256.65	12.34	257.48	12.91	258.40	12.98	259.50	13.06
261.08	13.18	252.95	13.32	264.27	13.41	264.80	13.44	270.50	13.63
271.99	13.94	272.70	13.99	274.24	14.09	275.35	14.17	275.76	14.20
278.15	14.23	276.77	14.27	277.00	14.29	277.27	14.31	278.40	14.39
281.41	14.60	274.15	14.80	235.65	14.92	288.78	15.09	289.17	15.14
290.72	15.25	291.63	15.31	292.00	15.33	292.37	15.38	295.57	15.55
296.17	15.59	299.50	15.77	302.73	16.00	315.02	16.51	315.05	16.51
310.20	16.55	319.83	16.59	335.05	17.31	335.39	17.32	345.13	17.66
345.74	17.69	347.42	17.73	349.85	17.80	353.86	17.91	356.07	17.93
360.75	18.12	364.00	18.25	368.07	18.25	401.70	19.14	405.00	19.21
406.00	19.27	407.00	19.25	408.00	19.27	409.00	19.29	410.00	19.30
411.00	19.31	412.00	19.32	413.00	19.33	414.00	19.34	415.00	19.35
416.00	19.35	417.00	19.36	417.24	19.37	417.71	19.37	418.00	19.37
419.00	19.39	420.00	19.40	421.00	19.42	422.70	19.44	423.00	19.46
424.00	19.48	425.00	19.50	426.00	19.53	427.00	19.55	428.00	19.57
425.00	19.57	430.00	19.60	430.50	19.61	471.00	19.61	432.00	19.62
433.00	19.63	434.00	19.64	435.00	19.64	436.00	19.65	436.10	19.65
437.00	19.66	433.00	19.67	439.00	19.68	440.00	19.70	441.00	19.72
442.00	19.67	443.00	19.78	444.00	19.81	445.00	19.84	446.00	19.88
447.00	19.91	448.00	19.94	449.00	19.97	450.00	20.00	451.00	20.02
452.00	20.04	453.00	20.05	454.00	20.03	455.00	20.10	456.00	20.11
457.00	20.17	459.00	20.15	459.00	20.17	460.00	20.20	461.00	20.23
462.00	20.25	463.00	20.30	464.00	20.34	465.10	20.38	465.92	20.39
466.00	20.43	467.00	20.47	468.00	20.51	469.10	20.56	469.80	20.59
471.00	20.67	471.00	20.64	472.00	20.58	473.00	20.72	474.00	20.75
475.00	20.80	476.00	20.34	477.00	20.33	478.00	20.52	479.00	20.55
480.00	21.00	401.00	21.04	492.00	21.09	482.10	21.09	483.00	21.14
484.00	21.19	485.00	21.23	486.00	21.28	487.00	21.34	488.00	21.39
485.00	21.44	489.50	21.47	490.00	21.50	491.00	21.56	492.00	21.61
493.00	21.67	494.00	21.73	495.00	21.79	496.00	21.85	497.00	21.91
496.00	21.97	499.00	22.04	499.27	22.05	500.00	22.10	501.00	22.16
502.00	22.27	503.00	22.30	504.00	22.37	507.00	22.68	515.60	23.57
521.10	23.52	525.00	23.65	532.03	25.20	542.30	25.68	550.00	25.40
534.51	25.55	553.00	25.78	552.80	25.71	566.50	25.85	572.30	25.23
560.40	24.03	584.33	22.01	599.00	26.52	608.00	26.58	609.00	26.32
565.85	24.17	610.00	26.10	611.00	25.73	612.00	25.75	613.00	25.73
614.00	25.63	615.00	25.60	616.00	25.59	616.60	25.59	617.00	25.60
616.00	25.62	619.00	25.56	620.00	25.70	621.00	25.75	622.00	25.73
622.00	25.87	624.00	25.37	625.00	25.39	625.20	25.90	626.00	25.91
627.00	25.91	623.00	25.90	627.00	25.86	629.73	25.82	630.00	25.80
631.00	25.72	632.00	25.61	633.00	25.60	634.00	25.67	635.00	25.24

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TABLE A-2 (continued)

λ	σ_T	λ	σ_T	λ	σ_T	λ	σ_T	λ	σ_T
866.00	11.92	869.00	11.94	870.00	12.02	871.00	12.04	872.00	12.05
873.00	9.00	874.00	7.50	875.00	6.02	876.00	5.84	877.00	5.65
878.00	9.49	879.00	9.31	880.00	9.15	881.00	9.01	882.00	8.90
883.00	8.27	884.00	11.41	885.00	11.35	886.00	11.31	887.00	11.29
888.00	11.29	889.00	11.27	890.00	11.28	891.00	7.55	892.00	7.61
893.00	7.64	894.00	7.68	895.00	7.71	896.00	7.74	897.00	4.79
898.00	4.62	909.00	4.34	900.00	17.57	901.00	17.56	902.00	17.53
903.00	17.59	904.00	17.57	904.10	17.57	905.00	17.55	906.00	4.82
907.00	17.75	908.00	17.72	909.00	17.69	910.00	17.65	911.00	17.60
914.00	17.55	913.00	17.50	914.00	17.45	915.00	4.43	916.00	4.38
917.00	14.26	918.00	14.30	919.00	14.24	920.00	14.18	921.00	14.12
922.00	14.04	923.00	3.96	923.10	3.65	924.00	13.52	925.00	13.47
926.00	13.41	926.20	13.40	927.00	13.35	928.00	13.30	929.00	13.25
930.00	3.57	930.70	3.54	931.00	25.74	932.00	25.69	933.00	25.64
933.00	25.62	934.00	25.60	935.00	25.55	936.00	25.51	937.00	3.27
937.00	3.24	938.00	23.56	939.00	21.53	940.00	23.50	941.00	23.47
942.00	23.44	943.00	23.42	944.00	23.40	945.00	23.35	946.00	30.16
946.00	30.14	947.00	30.13	948.00	30.11	949.00	30.10	950.74	30.09
950.00	30.09	951.00	30.07	952.00	2.95	953.00	2.94	954.00	2.93
955.00	28.57	956.00	28.52	957.00	28.51	958.00	28.50	959.00	28.48
960.00	28.44	961.00	27.11	962.00	27.09	963.00	27.07	964.00	27.04
965.00	27.02	966.00	27.00	967.00	26.97	968.00	26.95	969.00	26.92
970.00	26.87	971.00	26.36	972.00	21.96	972.50	21.95	973.00	21.93
974.00	21.97	975.00	21.37	976.00	21.34	977.00	21.30	977.00	21.80
978.00	21.77	979.00	21.74	980.00	21.71	981.00	21.67	982.00	21.64
981.00	22.09	984.00	22.34	985.00	22.31	986.00	22.78	987.00	22.74
988.00	22.71	989.00	22.66	990.00	22.64	991.00	1.93	991.00	1.93
992.00	1.90	993.00	1.37	994.00	13.07	995.00	13.04	996.00	13.01
997.00	12.53	998.00	1.72	999.00	1.691000.00	1.691001.00	1.691002.00	1.691003.00	1.691004.00
1002.00	1.611003.00		1.591004.00		1.611005.00		1.6761006.00		1.6761007.00
1007.00	3.711006.00		1.471009.00		1.471010.00		1.421011.00		1.421012.00
1011.00	1.401012.00		1.381013.00		1.351014.00		1.341015.00		1.341016.00
1016.00	1.201017.00		1.271018.00		1.251019.00		1.231020.00		1.211021.00
1021.00	1.131021.00		1.161022.00		1.151023.00		1.141024.00		1.121025.00
1025.00	1.091025.72		1.051026.00		1.071027.00		1.041028.00		1.021029.00
1029.00	1.071030.00		0.97						

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TABLE A-3

MOLECULAR OXYGEN PHOTOIONIZATION CROSS SECTIONS σ_I (Mb)

λ	σ_I								
14.25	.29	14.40	.29	15.01	.29	15.25	.29	16.01	.29
16.77	.29	17.05	.29	17.11	.29	18.52	.29	18.97	.29
21.60	.29	21.80	.29	22.10	.29	28.47	.30	28.79	.30
29.52	.30	30.02	.30	30.43	.30	33.74	.30	40.95	.31
40.78	.31	44.02	.31	44.16	.31	45.66	.31	46.40	.31
45.67	.34	47.67	.39	49.22	.42	50.36	.45	50.52	.45
50.69	.46	52.30	.50	52.91	.51	54.15	.54	54.42	.55
54.70	.55	55.06	.57	55.34	.57	56.08	.59	56.92	.61
57.76	.62	57.56	.63	57.88	.64	58.96	.66	59.62	.68
60.30	.70	60.85	.71	61.07	.72	61.53	.73	61.90	.74
62.30	.75	62.05	.75	62.77	.75	62.97	.76	63.16	.77
63.30	.77	63.05	.78	63.72	.78	64.11	.79	64.60	.80
65.21	.82	65.71	.83	65.85	.84	66.30	.85	67.14	.87
67.35	.87	68.35	.91	69.65	.75	70.00	.96	70.54	.98
70.75	.98	71.00	.99	71.94	1.01	72.31	1.02	72.53	1.03
72.80	1.04	72.95	1.04	73.55	1.06	74.21	1.06	74.44	1.08
74.83	1.11	75.03	1.10	75.29	1.11	75.46	1.11	75.73	1.12
76.01	1.13	76.48	1.14	76.63	1.15	76.94	1.15	77.30	1.16
77.74	1.19	78.56	1.20	79.70	1.20	79.78	1.21	79.43	1.23
79.76	1.23	80.00	1.24	80.21	1.25	80.55	1.26	80.94	1.27
81.16	1.27	81.56	1.28	81.94	1.29	82.43	1.31	82.67	1.31
83.25	1.37	83.42	1.34	83.67	1.34	84.70	1.35	84.26	1.35
84.50	1.37	84.72	1.37	84.86	1.38	85.16	1.38	85.50	1.39
85.69	1.40	85.87	1.40	86.23	1.41	86.40	1.42	86.77	1.43
86.96	1.44	87.30	1.44	87.61	1.45	88.10	1.47	88.11	1.47
88.14	1.47	88.42	1.46	88.64	1.48	89.90	1.49	89.14	1.50
89.70	1.51	90.14	1.52	90.45	1.53	90.71	1.54	91.00	1.55
91.46	1.56	91.65	1.57	91.81	1.57	92.09	1.58	92.55	1.59
92.61	1.60	93.61	1.62	94.07	1.63	94.25	1.64	94.37	1.64
94.81	1.65	94.90	1.66	95.37	1.67	95.51	1.67	95.81	1.69
98.03	1.66	98.49	1.70	98.63	1.71	97.12	1.72	97.51	1.73
98.97	1.74	99.12	1.75	99.23	1.75	99.50	1.76	98.83	1.77
99.44	1.78	99.71	1.79	99.99	1.80	100.34	1.84	100.75	1.86
101.57	1.97	102.15	1.94	103.01	2.00	103.15	2.01	103.17	2.01
103.54	2.04	103.94	2.06	104.23	2.08	104.76	2.11	105.23	2.15
105.25	2.21	105.57	2.23	106.93	2.26	108.75	2.33	108.45	2.35
105.50	2.43	105.98	2.46	110.55	2.50	110.52	2.50	110.76	2.51
111.16	2.57	111.25	2.54	113.80	2.71	114.09	2.73	114.24	2.74
115.37	2.82	115.52	2.84	116.73	2.91	117.27	2.94	120.40	3.15
121.15	3.20	121.75	3.24	122.70	3.30	123.50	3.35	127.63	3.62
125.97	3.77	130.50	3.92	131.02	3.96	131.21	3.97	136.21	4.25
136.26	4.27	136.34	4.27	136.45	4.23	136.49	4.28	144.21	4.79
145.06	5.85	148.38	5.09	150.10	5.21	152.13	5.33	152.34	5.39
154.20	5.85	157.73	5.66	158.33	5.70	159.94	5.80	164.13	5.98
161.50	6.32	163.17	6.37	168.55	6.40	168.72	6.42	171.03	6.58
172.12	6.65	172.92	6.71	173.19	6.72	174.53	6.82	175.24	6.87
175.47	6.89	177.22	7.01	178.02	7.05	179.72	7.18	180.40	7.22
180.71	7.27	181.14	7.27	182.16	7.33	182.59	7.34	183.91	7.44
184.10	7.45	184.52	7.47	184.76	7.49	185.21	7.52	186.60	7.60
186.77	7.67	183.28	7.70	188.70	7.72	190.00	7.87	191.29	7.87
192.36	7.93	192.90	7.96	193.53	8.00	195.14	8.04	196.60	8.13

TABLE A-3 (continued)

λ	σ_I								
157.41	8.23	159.53	8.30	200.00	6.40	201.10	9.46	202.64	8.60
200.78	9.60	204.69	8.78	206.24	8.90	206.38	9.91	207.46	9.00
208.33	9.07	209.63	9.17	209.73	9.18	209.93	9.19	211.32	9.30
212.15	9.34	214.75	9.54	215.15	9.57	216.90	9.68	218.21	9.77
215.09	9.83	220.08	9.91	221.25	9.79	221.51	10.01	223.26	10.15
223.72	10.19	224.81	10.27	225.12	10.30	227.01	10.45	227.47	10.49
226.79	10.67	230.65	10.75	231.55	10.93	232.60	10.91	233.84	11.01
234.38	11.05	235.55	11.15	237.16	11.29	239.87	11.49	240.73	11.56
240.03	11.74	245.94	11.97	246.24	12.00	246.91	12.05	247.13	12.07
249.23	12.24	251.10	12.39	251.96	12.46	252.17	12.48	253.80	12.61
256.37	12.82	256.65	12.84	257.48	12.91	258.40	12.92	259.50	13.06
261.08	13.19	262.99	13.32	264.27	13.41	264.30	13.44	270.50	13.83
271.99	13.54	272.70	13.95	274.24	14.09	275.35	14.17	275.76	14.20
276.15	14.23	276.77	14.27	277.00	14.29	277.27	14.31	278.40	14.39
281.41	14.60	284.15	14.80	285.85	14.92	288.34	15.09	289.17	15.14
290.72	15.25	291.63	15.31	292.00	15.33	292.37	15.38	295.57	15.55
296.17	15.59	299.50	15.77	303.78	16.00	313.02	16.51	315.05	16.51
316.20	16.55	319.93	16.69	335.05	17.31	335.39	17.32	345.13	17.66
345.74	17.69	347.42	17.73	349.85	17.80	353.86	17.91	356.07	17.99
360.76	18.12	364.80	18.25	368.07	18.35	401.70	19.14	405.00	19.21
406.00	19.23	407.00	19.25	403.00	19.27	409.00	19.29	410.00	19.30
411.00	19.31	412.00	19.32	413.00	19.23	414.00	19.34	415.00	19.35
416.00	19.34	417.00	19.36	417.24	19.37	417.71	19.37	418.00	19.37
419.00	19.39	420.00	19.40	421.00	19.42	422.00	19.44	423.00	19.46
424.00	19.43	425.00	19.50	426.00	19.53	427.00	19.55	428.00	19.57
429.00	19.55	430.00	19.60	430.50	19.61	431.00	19.61	432.00	19.62
433.00	19.63	434.00	19.64	435.00	19.64	436.00	19.65	436.10	19.65
437.00	19.65	438.00	19.67	439.00	19.68	440.00	19.70	441.00	19.72
442.00	19.75	443.00	19.78	444.00	19.81	445.00	19.84	446.00	19.88
447.00	19.91	448.00	19.94	449.00	19.97	450.00	20.00	451.00	20.02
452.00	20.04	453.00	20.06	454.00	20.08	455.00	20.10	456.00	20.11
457.00	20.13	458.00	20.15	459.00	20.17	460.00	20.20	461.00	20.23
462.00	20.26	463.00	20.30	464.00	20.34	465.00	20.38	466.22	20.39
466.00	20.43	467.00	20.47	468.00	20.51	469.00	20.56	469.80	20.59
470.00	20.60	471.00	20.64	472.00	20.68	473.00	20.72	474.00	20.75
475.00	20.82	476.00	20.84	477.00	20.88	478.00	20.92	479.00	20.96
480.00	21.00	481.00	21.04	482.00	21.09	482.10	21.09	483.00	21.14
484.00	21.19	485.00	21.23	486.00	21.28	487.00	21.34	488.00	21.39
489.00	21.44	490.50	21.47	490.00	21.50	491.00	21.56	492.00	21.61
493.00	21.67	494.00	21.73	495.00	21.79	496.00	21.95	497.00	21.91
496.00	21.97	499.00	22.04	499.27	22.05	500.00	22.10	501.00	22.16
504.00	22.27	503.00	22.30	504.00	22.37	507.00	22.68	515.60	23.57
521.10	23.52	525.00	23.65	537.03	25.20	542.80	25.68	550.00	25.40
554.51	25.56	553.60	25.73	562.00	25.71	563.50	25.35	572.30	25.28
556.40	24.03	554.30	22.71	559.60	24.52	563.00	26.54	405.00	26.32
605.63	26.13	610.00	26.10	611.00	25.93	612.00	25.79	613.00	25.70
614.00	25.63	615.00	25.60	616.00	25.53	616.50	25.55	617.00	25.60
616.00	25.62	619.00	25.66	620.00	25.70	621.00	25.75	622.00	25.79
620.00	25.83	624.00	25.97	625.00	25.89	625.29	25.90	626.00	25.91
627.00	25.91	628.00	25.93	629.00	25.96	629.73	25.92	630.00	25.90
631.00	25.77	632.00	25.61	633.00	25.50	634.00	25.37	635.00	25.24

TABLE A-3 (continued)

λ	σ_I										
536.00	25.17	637.00	24.98	638.00	24.57	539.00	24.77	640.00	24.79		
541.00	24.65	642.00	24.63	643.00	24.53	644.00	24.64	644.10	24.64		
645.00	24.66	646.00	24.69	647.00	24.73	648.00	24.76	649.00	24.78		
550.00	23.07	551.00	23.06	552.00	23.11	553.10	23.14	554.00	23.16		
655.00	23.15	656.00	23.15	657.00	23.13	657.30	23.12	658.00	23.10		
659.00	23.05	660.00	22.99	661.00	22.92	661.40	22.88	662.00	22.83		
663.00	22.77	664.00	22.61	665.00	22.49	666.10	22.35	667.00	22.19		
668.00	22.07	669.00	21.35	670.00	21.65	671.00	21.45	671.50	21.34		
672.00	21.27	673.00	21.30	674.00	20.75	675.00	20.49	676.00	20.22		
677.00	19.53	678.00	19.64	679.00	19.32	680.00	19.00	680.94	18.23		
681.00	18.23	681.70	18.24	682.00	18.25	683.00	18.28	684.00	18.32		
685.00	18.39	685.70	18.43	686.00	14.45	687.00	14.54	688.00	14.65		
689.00	14.77	690.00	14.90	691.00	15.35	692.00	15.21	693.00	15.39		
694.00	15.58	694.30	15.54	695.00	15.79	696.00	15.01	697.00	16.25		
698.00	16.50	699.00	16.77	700.00	17.05	701.00	17.39	702.00	17.69		
703.00	17.93	703.40	18.02	704.00	18.15	705.00	19.32	706.00	18.46		
707.00	18.56	708.00	18.62	709.00	18.65	710.00	18.63	711.00	18.53		
712.00	19.49	712.70	18.40	713.00	18.56	714.00	13.15	715.00	17.59		
716.00	17.74	717.00	17.46	718.00	17.14	719.50	16.96	719.00	16.78		
721.00	16.32	721.00	18.14	722.00	18.71	723.00	19.21	724.00	19.64		
725.00	20.07	726.00	20.29	727.00	20.51	728.10	20.66	729.00	20.74		
730.00	20.75	731.00	20.70	732.00	20.57	733.00	20.38	734.00	20.11		
735.00	19.78	736.00	19.37	737.00	18.90	738.00	18.36	739.00	17.74		
740.00	17.04	741.00	16.31	742.00	15.49	743.00	14.60	744.00	13.64		
745.00	12.61	746.00	11.61	747.00	10.34	748.00	9.10	749.00	7.30		
750.00	6.47	751.00	8.52	752.00	8.55	753.00	8.50	754.00	8.46		
755.00	8.42	756.00	8.35	757.00	8.37	758.00	8.36	759.70	8.36		
759.00	8.34	759.40	8.36	760.00	8.37	760.40	8.37	761.00	8.33		
762.00	8.41	762.00	8.41	763.00	8.44	764.00	8.46	764.60	8.51		
765.00	8.54	766.00	8.50	767.00	8.56	768.00	8.74	769.00	8.83		
770.00	8.92	770.40	9.62	771.00	9.68	772.00	9.77	773.00	9.84		
774.00	9.57	775.00	9.95	776.00	9.57	776.00	9.95	777.00	10.01		
778.00	10.02	779.00	10.02	780.00	10.01	780.30	10.00	781.00	9.98		
782.00	9.94	783.00	9.39	784.00	9.93	785.00	9.75	786.00	9.66		
786.40	9.61	787.00	9.56	787.71	9.48	788.00	9.45	789.00	9.32		
790.00	5.69	790.21	5.65	791.00	5.52	792.00	5.38	793.00	5.26		
794.00	9.15	795.00	9.03	796.00	9.03	797.00	9.49	798.00	8.99		
795.00	8.59	800.00	9.02	801.00	9.07	802.00	9.15	803.00	9.24		
804.00	5.35	805.00	9.50	806.00	9.65	807.00	9.85	808.00	10.05		
805.00	10.23	810.00	10.52	811.00	11.85	812.00	11.50	813.00	11.11		
814.00	10.72	815.00	10.35	816.00	9.98	817.00	9.67	818.00	9.27		
815.00	5.92	820.00	8.59	821.00	8.25	822.00	7.93	823.00	7.62		
824.00	7.21	825.00	7.01	826.00	6.72	827.00	6.43	828.00	6.15		
825.00	5.68	826.00	5.62	827.00	6.63	828.00	5.71	829.00	6.54		
834.00	5.37	834.20	6.34	835.00	6.21	836.00	6.95	837.00	5.90		
836.00	5.73	839.00	5.60	840.00	5.46	841.00	5.32	842.00	5.19		
843.00	5.05	844.00	4.93	845.00	4.31	846.00	4.68	847.00	4.53		
846.00	4.47	849.00	4.36	850.00	4.26	851.00	4.16	852.00	4.07		
853.00	3.97	854.00	3.39	855.00	3.93	856.00	3.72	857.00	3.65		
856.00	3.59	859.00	3.51	860.00	3.42	861.00	3.02	862.00	3.03		
866.00	3.07	864.00	3.07	865.00	3.02	866.00	3.17	867.00	3.12		

TABLE A-3 (continued)

λ	σ_I								
860.00	3.13	869.00	3.15	870.00	3.17	871.00	3.18	872.00	3.20
870.00	3.22	874.00	3.24	875.00	3.25	876.00	3.27	877.00	3.29
876.00	3.27	879.00	3.32	880.00	3.34	881.00	3.36	882.00	3.38
883.00	3.39	884.00	3.41	885.00	3.43	886.00	3.45	887.00	3.46
886.00	3.49	889.00	3.49	890.00	3.50	891.00	3.51	892.00	3.52
893.00	3.53	894.00	3.54	895.00	3.54	896.00	3.54	897.00	3.54
898.00	3.54	899.00	3.53	900.00	3.52	901.00	3.51	902.00	3.50
903.00	3.49	904.00	3.46	904.10	3.46	905.00	3.44	906.00	3.42
907.00	3.30	908.00	3.36	909.00	3.34	910.00	3.31	911.00	3.23
912.00	3.25	913.00	3.21	914.00	3.12	915.00	3.15	916.00	3.12
917.00	3.09	918.00	3.06	919.00	3.03	920.00	3.00	921.00	2.97
922.00	2.95	923.00	2.92	923.10	2.92	924.00	2.90	925.00	2.88
926.00	2.85	926.20	2.85	927.00	2.83	928.00	2.81	929.00	2.79
930.00	2.77	930.70	2.75	931.00	2.75	932.00	2.73	933.00	2.71
933.40	2.77	934.00	2.69	935.00	2.67	936.00	2.65	937.00	2.62
937.90	2.61	939.00	2.60	939.00	2.58	940.00	2.56	941.00	2.53
944.00	2.51	945.00	2.43	946.00	2.45	947.00	2.44	948.00	2.43
946.00	2.40	947.00	2.37	948.00	2.34	949.00	2.32	950.74	2.30
950.00	2.29	951.00	2.26	952.00	2.24	953.00	2.21	954.00	2.19
955.00	2.15	956.00	2.14	957.00	2.12	958.00	2.10	959.00	2.08
960.00	2.06	961.00	2.05	962.00	2.03	963.00	2.02	964.00	2.01
965.00	2.00	966.00	1.99	967.00	1.93	968.00	1.97	969.00	1.96
970.00	1.95	971.00	1.95	972.00	1.94	972.50	1.92	973.00	1.93
974.00	1.92	975.00	1.91	976.00	1.90	977.00	1.89	977.03	1.89
976.00	1.88	977.00	1.87	978.00	1.85	981.00	1.84	982.00	1.82
983.00	1.80	984.00	1.78	985.00	1.76	986.00	1.74	987.00	1.72
988.00	1.69	989.00	1.67	990.00	1.55	991.00	1.62	991.00	1.62
992.00	1.67	993.00	1.58	994.00	1.55	995.00	1.53	996.00	1.50
997.00	1.48	998.00	1.43	999.00	1.44	1000.00	1.42	1001.00	1.40
1002.00	1.31	1003.00	1.36	1004.00	1.35	1005.00	1.33	1006.00	1.32
1007.00	1.21	1008.00	1.24	1009.00	1.27	1010.00	1.26	1011.00	1.26
1011.00	1.21	1012.00	1.24	1013.00	1.23	1014.00	1.21	1015.00	1.20
1016.00	1.17	1017.00	1.18	1018.00	1.17	1019.00	1.16	1020.00	1.15
1021.00	1.17	1021.00	1.13	1022.00	1.12	1023.00	1.11	1024.00	1.10
1022.00	1.08	1023.00	0.98	1024.00	1.07	1025.00	1.06	1026.00	0.00
1025.00	0.00	1027.00	0.03						

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TABLE A-5

MOLECULAR NITROGEN ABSORPTION CROSS SECTIONS σ_T (Mb)

λ	σ_T								
14.75	0.03	14.40	0.03	15.01	0.03	15.26	0.03	16.01	0.04
16.77	0.04	17.05	0.04	17.11	0.04	18.52	0.05	18.97	0.05
21.60	0.06	21.80	0.06	22.10	0.06	28.47	0.09	28.79	0.09
29.52	0.10	30.02	0.10	30.43	0.10	33.74	0.11	40.95	0.14
42.76	0.16	44.02	0.16	44.15	0.16	45.64	0.20	46.40	0.21
46.67	0.21	47.87	0.23	49.22	0.24	50.36	0.26	50.52	0.25
50.59	0.25	52.30	0.29	52.91	0.29	54.15	0.31	54.42	0.32
54.70	0.32	55.06	0.32	55.74	0.33	56.75	0.34	56.92	0.35
57.36	0.36	57.56	0.36	57.68	0.36	58.36	0.38	59.62	0.39
60.30	0.47	60.85	0.40	61.07	0.41	61.57	0.41	61.90	0.42
62.33	0.42	62.35	0.42	62.77	0.47	62.92	0.43	63.16	0.44
63.30	0.44	63.65	0.44	63.72	0.44	64.11	0.45	64.60	0.46
65.21	0.45	65.71	0.47	65.85	0.47	66.30	0.48	67.14	0.49
67.35	0.49	69.35	0.50	69.65	0.52	70.00	0.52	70.54	0.53
70.73	0.53	71.00	0.53	71.94	0.54	72.31	0.55	72.53	0.55
72.80	0.55	72.95	0.55	73.55	0.56	74.21	0.57	74.44	0.57
74.83	0.57	75.03	0.58	75.29	0.58	75.46	0.58	75.73	0.58
76.01	0.59	76.48	0.59	76.63	0.59	76.94	0.60	77.70	0.60
77.74	0.61	78.56	0.61	78.77	0.61	79.78	0.62	79.48	0.62
79.70	0.63	80.00	0.63	80.21	0.63	80.55	0.63	80.94	0.64
81.13	0.64	81.56	0.64	81.94	0.65	82.43	0.65	82.67	0.66
82.25	0.65	83.42	0.66	83.67	0.67	84.30	0.67	84.26	0.67
84.50	0.69	84.72	0.68	84.86	0.68	85.16	0.68	85.50	0.69
85.67	0.69	85.97	0.59	86.23	0.69	86.40	0.70	86.77	0.70
86.96	0.77	87.30	0.71	87.61	0.71	88.10	0.71	88.11	0.71
88.14	0.71	89.42	0.72	89.64	0.72	89.90	0.72	89.14	0.72
89.70	0.77	90.14	0.74	90.45	0.74	90.71	0.74	91.00	0.74
91.45	0.75	91.55	0.75	91.81	0.75	92.05	0.76	92.55	0.76
92.81	0.76	93.61	0.77	94.07	0.73	94.25	0.78	94.39	0.79
94.91	0.78	94.90	0.79	95.37	0.79	95.51	0.79	95.81	0.80
96.03	0.80	96.45	0.80	96.83	0.81	97.12	0.81	97.51	0.81
97.67	0.82	98.12	0.82	98.23	0.82	98.50	0.82	98.80	0.83
99.44	0.83	99.71	0.84	99.99	0.84	100.34	0.87	100.93	0.89
101.57	0.97	102.15	0.96	102.01	1.01	103.15	1.02	103.17	1.02
103.78	1.04	103.94	1.06	104.23	1.09	104.76	1.10	105.23	1.13
106.25	1.10	106.57	1.21	106.93	1.23	108.05	1.29	108.45	1.31
109.50	1.37	109.96	1.30	110.55	1.43	113.52	1.43	113.76	1.44
111.50	1.45	111.25	1.47	113.83	1.61	114.07	1.62	114.24	1.63
115.37	1.70	115.32	1.72	116.75	1.77	117.20	1.80	120.43	1.97
121.15	2.00	121.75	2.05	122.70	2.10	123.70	2.15	127.65	2.38
125.57	2.57	128.80	2.47	131.02	2.51	131.21	2.57	136.21	2.79
131.25	2.79	136.34	2.80	136.43	2.90	136.43	2.80	144.21	3.25
141.70	3.27	143.88	3.50	150.10	3.61	152.15	3.71	152.84	3.78
154.20	3.85	157.73	4.07	158.23	4.11	159.54	4.20	164.12	4.42
167.50	4.61	163.17	4.64	132.55	4.87	168.92	4.68	171.76	4.81
172.12	4.83	172.52	4.93	173.10	4.94	174.52	5.04	175.24	5.03
175.47	5.10	177.22	5.22	178.02	5.27	179.74	5.36	180.40	5.37
186.71	5.39	181.14	5.40	132.16	5.45	192.32	5.46	133.91	5.52
184.10	5.57	184.32	5.55	194.75	5.56	185.21	5.56	186.60	5.64
186.97	5.65	193.20	5.71	130.70	5.74	190.70	5.80	191.29	5.87
192.30	5.97	192.60	5.95	197.50	5.95	195.14	6.09	196.60	6.19

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TABLE A-5 (continued)

λ	σ_T								
17.041	6.027	193.052	6.30	200.000	6.40	201.017	6.45	202.064	6.59
202.070	6.067	204.085	6.75	206.025	6.85	206.038	6.95	207.046	6.93
208.033	6.059	209.033	7.02	209.073	7.03	209.093	7.10	211.032	7.13
212.015	7.027	214.075	7.39	215.015	7.41	216.000	7.51	218.021	7.59
215.009	7.064	220.008	7.71	221.026	7.78	221.051	7.80	223.026	7.92
220.072	7.055	224.081	8.03	225.012	8.05	227.001	8.15	227.047	8.22
225.079	8.032	230.055	8.44	231.055	8.51	232.050	8.58	233.024	8.65
234.030	8.069	235.055	8.76	237.036	8.86	239.097	8.95	240.073	9.03
243.003	9.014	245.094	9.25	246.024	9.26	246.011	9.29	247.013	9.30
247.020	9.037	251.010	9.44	251.096	9.47	252.017	9.48	251.090	9.54
256.037	9.067	256.059	9.66	257.048	9.69	258.040	9.73	259.050	9.73
261.006	9.085	262.099	9.93	264.027	9.59	264.000	10.01	270.050	10.21
271.029	10.021	272.070	10.26	274.024	10.23	275.035	10.30	275.076	10.30
276.015	10.031	276.077	10.32	277.000	10.33	277.027	10.33	278.040	10.35
281.041	10.045	284.015	10.53	285.025	10.67	288.036	10.81	289.017	10.85
290.072	10.094	291.003	10.95	292.000	11.00	292.083	11.05	295.057	11.13
296.017	11.021	299.050	11.37	303.078	11.61	315.022	12.06	315.005	12.06
314.020	12.045	319.083	12.73	335.005	13.07	335.039	14.071	345.013	15.069
345.074	15.095	347.042	16.14	349.085	16.39	353.066	16.77	354.007	16.95
360.076	17.025	364.030	17.69	366.007	17.95	401.070	20.11	405.000	20.32
406.000	20.033	407.000	20.44	409.000	20.49	409.000	20.55	410.000	20.60
411.000	20.065	412.000	20.69	413.000	20.74	414.000	20.78	415.000	20.83
416.000	20.089	417.000	20.93	417.024	20.94	417.071	20.96	418.000	20.98
419.000	21.004	420.000	21.10	421.000	21.17	422.000	21.24	423.000	21.32
424.000	21.040	425.000	21.43	426.000	21.56	427.000	21.63	428.000	21.69
429.000	21.075	430.000	21.30	430.050	21.62	431.000	21.34	432.000	21.87
430.000	21.083	434.000	21.90	435.000	21.90	436.000	21.90	436.010	21.90
432.000	21.097	433.000	21.90	435.000	21.90	440.000	21.90	441.000	21.90
442.000	21.091	443.000	21.92	444.000	21.92	445.000	21.94	446.000	21.95
447.000	21.095	443.000	21.97	449.000	21.99	450.000	22.00	451.000	22.01
452.000	22.002	453.000	22.03	454.000	22.04	455.000	22.04	456.000	22.04
457.000	22.004	453.000	22.03	435.000	22.02	460.000	22.00	461.000	21.98
462.000	21.055	463.000	21.31	464.000	21.35	465.000	21.34	465.022	21.24
466.000	21.081	467.000	21.73	468.000	21.75	469.000	21.72	469.050	21.70
470.000	21.070	471.000	21.65	472.000	21.68	473.000	21.67	474.000	21.67
475.000	21.069	476.000	21.68	477.000	21.69	478.000	21.65	475.000	21.70
480.000	21.077	481.000	21.70	482.000	21.70	482.010	21.70	482.000	21.69
484.000	21.069	485.000	21.56	486.000	21.65	487.000	21.68	486.000	21.63
485.000	21.069	489.050	21.65	490.000	21.70	491.000	21.72	492.000	21.74
491.000	21.077	494.000	21.60	495.000	21.63	496.000	21.68	497.000	21.60
498.000	21.054	499.000	21.97	499.027	21.99	500.010	22.00	501.000	22.03
502.000	22.005	503.000	22.05	504.000	22.12	507.040	22.40	515.060	23.59
521.010	25.019	525.030	25.59	537.003	25.30	542.000	25.19	550.000	25.10
554.051	28.074	573.060	24.32	562.080	24.02	568.050	23.77	572.030	23.67
560.040	23.013	584.070	23.21	592.060	23.11	598.000	23.08	605.000	23.09
605.025	23.017	610.000	23.10	611.000	23.11	612.000	23.12	613.000	23.14
614.000	23.015	615.000	23.16	616.000	23.17	616.600	23.16	617.000	23.18
616.000	23.010	619.000	23.20	620.000	23.20	621.000	23.20	622.000	23.20
626.000	23.020	624.000	23.20	625.000	23.20	625.200	23.20	626.000	23.20
627.000	23.017	623.000	23.17	625.000	23.20	625.700	23.20	630.000	23.20
631.000	23.021	672.000	23.21	633.000	23.23	634.000	23.24	635.000	23.25

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TABLE A-5 (continued)

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530.00	23.24	677.00	23.27	638.00	27.28	639.00	23.29	740.00	23.30
441.00	23.31	642.00	23.31	643.00	23.31	644.00	23.31	644.10	23.31
645.00	23.31	646.00	23.31	647.00	23.30	648.00	23.30	649.00	23.30
650.00	23.30	651.00	23.30	652.00	24.10	653.00	24.52	654.00	24.94
555.00	25.25	656.00	25.77	657.00	26.14	658.00	26.25	659.00	26.49
657.00	26.07	660.00	27.00	661.00	27.17	662.00	27.21	663.00	27.27
663.00	27.03	664.00	27.34	665.00	27.33	666.00	27.29	667.00	27.24
666.00	27.05	669.00	30.72	670.00	30.69	671.00	33.86	671.50	33.85
674.00	33.87	673.00	35.59	674.00	27.14	675.00	35.14	676.00	35.15
677.00	35.17	673.00	27.19	679.00	27.16	680.00	23.91	680.94	23.92
581.00	23.82	681.70	30.07	682.00	38.03	683.00	37.88	684.00	37.71
585.00	26.83	685.70	28.25	686.00	26.20	687.00	26.01	688.00	25.83
687.00	25.64	689.00	22.01	691.00	22.13	692.00	22.07	693.00	43.49
694.00	43.04	694.30	43.43	695.00	43.41	696.00	43.42	697.00	43.45
698.00	25.62	699.00	25.34	700.00	25.50	701.00	25.70	702.00	25.54
703.00	26.02	703.40	26.34	704.00	25.32	705.00	25.85	706.00	27.20
707.00	27.05	708.00	27.34	709.00	25.32	710.00	28.70	711.00	29.03
712.00	25.04	712.67	29.65	713.00	25.90	714.00	30.12	715.00	36.78
716.00	37.07	717.00	37.02	718.00	31.01	719.00	71.06	719.00	31.09
720.00	31.17	721.00	31.03	722.00	57.17	723.00	56.92	724.00	56.57
725.00	56.10	726.00	55.52	727.00	54.80	728.00	27.66	729.00	26.66
730.00	25.50	731.00	24.61	732.00	22.73	733.00	21.32	734.00	27.07
735.00	7.17	735.00	33.69	737.00	26.82	738.00	33.02	739.00	23.71
746.00	25.62	741.00	29.26	742.00	25.26	743.00	20.97	744.00	25.45
745.00	29.64	746.00	29.45	747.00	25.45	748.00	22.63	749.00	29.31
750.00	28.84	751.00	24.67	752.00	24.70	753.00	17.73	754.00	17.73
755.00	31.65	756.00	31.96	757.00	31.93	758.00	32.16	759.70	32.16
759.00	25.09	759.40	36.09	760.00	26.09	760.40	30.27	761.00	30.27
762.00	30.27	762.00	30.27	763.00	30.27	764.00	19.64	764.60	18.64
765.00	35.64	766.00	35.47	767.00	35.47	768.00	9.72	769.00	5.72
770.00	5.67	770.40	9.67	771.00	5.67	772.00	26.88	773.00	26.83
774.00	26.68	775.00	26.68	776.00	36.25	776.00	47.10	777.00	47.10
775.00	47.61	779.00	47.10	780.00	24.67	780.30	24.67	781.00	24.67
782.00	40.67	783.00	40.67	784.00	54.83	785.00	64.83	786.00	54.83
786.04	16.62	787.00	16.26	787.71	16.26	788.00	16.26	789.00	16.26
790.00	25.62	790.21	29.21	791.00	25.21	792.00	59.86	793.00	55.86
794.00	59.64	795.00	25.77	796.00	26.97	797.00	26.97	798.00	26.25
795.00	7.62	800.00	5.92	801.00	5.63	802.00	45.08	803.00	45.05
804.00	6.07	805.00	29.55	806.00	6.00	807.00	21.80	808.00	44.82
809.00	42.65	910.00	23.36	811.00	6.00	812.00	0.00	813.00	0.00
814.00	35.61	813.00	35.61	814.00	75.91	817.00	0.00	818.00	0.00
815.00	1.00	816.00	45.63	817.00	45.63	822.00	0.00	823.00	16.00
824.00	16.00	825.00	7.63	826.00	4.63	827.00	15.73	828.00	15.73
825.00	15.67	826.00	6.00	831.00	6.00	832.00	0.00	833.00	6.00
834.00	6.07	834.20	6.00	835.00	6.00	836.00	1.30	837.00	32.00
835.00	32.00	839.00	3.31	840.00	8.81	841.00	8.81	842.00	23.63
842.00	21.65	844.00	21.63	845.00	21.53	846.00	10.97	847.00	10.97
846.00	10.97	849.00	5.61	850.00	5.61	851.00	13.82	852.00	13.82
852.00	13.62	854.00	11.62	855.00	36.12	856.00	35.42	857.00	34.42
858.00	53.60	859.00	29.64	860.00	29.94	861.00	29.84	862.00	9.36
860.00	9.65	864.00	9.63	865.00	16.01	866.00	16.01	867.00	54.65

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TABLE A-5 (continued)

λ	σ_T								
866.00	41.97	869.00	41.97	870.00	41.97	871.00	41.97	872.00	36.90
873.00	37.94	874.00	37.96	875.00	37.96	876.00	37.96	877.00	47.87
878.00	47.87	879.00	47.87	880.00	47.87	881.00	47.87	882.00	63.18
883.00	53.19	884.00	63.18	885.00	63.13	886.00	60.00	887.00	45.66
888.00	176.16	889.00	176.16	890.00	5.37	891.00	9.37	892.00	45.71
893.00	45.71	894.00	45.71	895.00	10.26	896.00	10.26	897.00	10.26
898.00	51.92	899.00	106.06	900.00	106.06	901.00	18.11	902.00	18.11
903.00	22.77	904.00	19.25	904.10	203.78	905.00	203.78	906.00	18.04
907.00	18.04	908.00	18.04	909.00	11.62	910.00	11.62	911.00	11.62
912.00	14.52	913.00	14.50	914.00	40.92	915.00	40.92	916.00	40.92
917.00	40.92	918.00	10.04	919.00	10.04	920.00	10.04	921.00	95.77
922.00	95.77	923.00	55.55	923.10	31.92	924.00	31.92	925.00	31.92
926.00	31.92	926.20	19.03	927.00	15.03	928.00	19.03	929.00	19.03
930.00	64.51	930.70	64.51	931.00	64.51	932.00	64.51	933.00	3.13
933.40	3.13	934.00	3.13	935.00	3.13	936.00	3.13	937.00	2.94
937.90	3.15	938.00	3.15	939.00	3.15	940.00	120.77	941.00	120.77
942.00	120.77	943.00	120.77	944.00	34.73	944.50	39.78	945.00	39.73
946.00	39.73	947.00	39.78	948.00	0.00	949.00	0.00	949.74	0.00
950.00	7.16	951.00	7.16	952.00	7.16	953.00	7.16	954.00	7.16
955.00	7.14	956.00	7.16	957.00	15.89	958.00	15.89	959.00	15.89
960.00	260.79	961.00	260.78	962.00	54.37	963.00	56.67	964.00	56.87
965.00	56.87	966.00	56.37	967.00	62.17	968.00	63.37	969.00	63.37
970.00	62.37	971.00	63.37	972.00	63.37	972.50	63.11	973.00	58.11
974.00	43.11	975.00	48.11	976.00	61.11	977.00	68.11	977.03	68.11
978.00	68.11	979.00	68.11	980.00	44.22	981.00	44.22	982.00	44.22
981.00	44.22	984.00	44.22	985.00	44.22	986.00	44.22		

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TABLE A-6

MOLECULAR NITROGEN PHOTOIONIZATION CROSS SECTIONS σ_I (Mb)

λ	σ_I										
14.25	.03	14.40	.03	15.01	.03	15.26	.03	16.01	.04		
16.77	.04	17.05	.04	17.11	.04	18.52	.05	18.97	.05		
21.60	.06	21.60	.06	22.10	.06	26.47	.09	28.79	.09		
25.52	.10	29.02	.10	30.43	.10	33.74	.11	40.95	.14		
43.76	.15	44.04	.16	44.15	.16	45.56	.20	46.40	.21		
46.61	.21	47.37	.23	49.22	.24	50.36	.26	50.52	.26		
50.69	.26	52.30	.29	52.91	.29	54.15	.31	54.42	.32		
54.70	.32	55.00	.32	55.34	.33	56.08	.34	56.52	.35		
57.76	.35	57.56	.36	57.83	.36	58.96	.38	59.62	.39		
60.70	.40	61.85	.40	61.07	.41	61.63	.41	61.90	.42		
62.30	.42	62.35	.42	62.77	.43	62.92	.43	63.16	.44		
63.70	.44	63.65	.44	63.72	.44	64.11	.45	64.60	.46		
65.21	.46	65.71	.47	65.85	.47	66.30	.48	67.14	.49		
67.35	.49	68.05	.50	69.65	.52	70.00	.52	70.54	.53		
70.75	.53	71.00	.53	71.94	.54	72.31	.55	72.63	.55		
72.80	.55	72.95	.55	73.55	.55	74.21	.57	74.44	.57		
74.85	.57	75.03	.58	75.29	.58	75.46	.58	75.73	.58		
76.01	.59	76.48	.59	76.83	.59	76.94	.60	77.30	.60		
77.74	.60	78.56	.61	78.70	.61	79.78	.62	79.48	.62		
79.70	.63	80.00	.63	80.21	.63	80.55	.63	80.94	.64		
81.10	.64	81.58	.64	81.94	.65	82.43	.65	82.67	.66		
83.25	.65	83.42	.66	83.67	.67	84.02	.67	84.26	.67		
84.50	.69	84.72	.68	84.86	.68	85.16	.68	85.50	.69		
85.65	.69	85.87	.69	86.23	.69	86.47	.70	86.77	.70		
86.95	.70	87.30	.71	87.61	.71	88.10	.71	88.11	.71		
88.14	.71	88.42	.72	88.64	.72	88.90	.72	88.14	.72		
89.70	.72	89.14	.74	90.45	.74	90.71	.74	91.00	.74		
91.48	.75	91.69	.75	91.81	.75	92.09	.76	92.55	.76		
92.81	.76	93.61	.77	94.07	.78	94.25	.78	94.35	.78		
94.81	.79	94.96	.79	95.37	.79	95.51	.79	95.81	.80		
96.70	.87	96.49	.80	96.63	.81	97.12	.81	97.51	.81		
97.87	.87	98.12	.82	98.23	.82	98.50	.82	98.88	.83		
98.44	.83	99.71	.84	99.59	.84	100.54	.87	100.56	.89		
101.57	.93	102.15	.96	103.01	1.01	103.15	1.02	103.17	1.02		
103.56	1.04	103.94	1.06	104.23	1.08	104.76	1.10	105.23	1.13		
106.20	1.09	106.57	1.21	106.93	1.23	108.05	1.29	108.46	1.31		
108.57	1.37	109.96	1.39	110.56	1.43	110.62	1.43	110.76	1.44		
111.10	1.45	111.25	1.47	113.80	1.61	114.07	1.62	114.24	1.63		
111.39	1.77	115.82	1.72	116.75	1.77	117.20	1.90	120.40	1.97		
121.10	2.02	121.79	2.05	122.70	2.10	123.50	2.15	127.65	2.38		
125.97	2.50	129.20	2.47	131.02	2.51	131.21	2.52	136.21	2.79		
134.26	2.72	176.34	2.80	136.45	2.80	136.48	2.80	144.21	3.25		
145.00	3.22	143.05	3.50	150.10	3.51	152.15	3.73	152.94	3.78		
154.20	3.84	157.73	4.07	158.38	4.11	155.94	4.20	154.13	4.42		
167.50	4.61	153.17	4.54	168.55	4.67	166.72	4.69	171.06	4.81		
172.12	4.89	172.92	4.93	173.10	4.94	174.33	5.04	175.24	5.03		
175.07	5.17	177.22	5.22	179.02	5.27	179.74	5.30	180.40	5.37		
180.71	5.38	181.14	5.40	182.15	5.45	182.39	5.46	182.91	5.52		
184.10	5.53	184.52	5.55	184.76	5.58	185.21	5.58	186.60	5.64		
188.87	5.45	189.23	5.71	189.70	5.74	190.00	5.80	191.29	5.87		
192.75	5.97	192.80	5.95	193.50	5.95	195.14	5.95	196.63	6.18		

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TABLE A-6 (continued)

λ	σ_I								
197.41	6.23	198.52	6.30	200.00	6.40	201.10	6.48	202.64	6.59
203.78	6.67	204.85	6.75	206.26	6.85	206.38	6.85	207.46	6.93
206.73	6.99	209.63	7.08	209.73	7.09	209.93	7.10	211.32	7.19
212.15	7.23	214.75	7.39	215.16	7.41	216.00	7.51	216.21	7.59
215.09	7.64	220.00	7.71	221.25	7.78	221.51	7.89	223.26	7.92
223.74	7.95	224.61	8.03	225.12	8.05	227.01	8.19	227.47	8.22
226.79	8.22	230.65	8.44	231.55	8.51	232.60	8.58	233.84	8.65
234.36	8.69	235.55	8.76	237.36	8.86	239.87	8.99	240.73	9.03
243.03	9.14	245.94	9.25	246.24	9.26	246.71	9.29	247.18	9.30
245.23	9.37	251.10	9.44	251.96	9.47	252.17	9.48	253.90	9.54
256.37	9.65	255.69	9.56	257.48	9.69	258.49	9.73	259.50	9.73
261.08	9.85	262.94	9.93	264.27	9.99	264.80	10.01	270.50	10.21
271.99	10.24	272.70	10.26	274.24	10.28	275.35	10.30	275.76	10.30
276.15	10.71	276.77	10.32	277.03	10.33	277.27	10.33	278.49	10.35
281.41	10.45	284.15	10.58	295.85	10.67	298.36	10.81	299.17	10.85
290.72	10.94	291.63	10.99	292.00	11.00	292.93	11.05	295.57	11.13
296.17	11.21	299.50	11.37	303.73	11.61	315.02	12.36	315.05	12.36
316.20	12.45	319.83	12.78	335.05	14.67	335.35	14.71	345.13	15.89
345.74	15.95	347.42	16.14	349.85	16.39	353.36	16.77	356.07	16.96
350.76	17.34	364.30	17.59	368.07	17.55	401.70	20.11	405.00	20.32
406.00	20.39	407.00	20.44	408.00	20.49	409.00	20.55	410.00	20.60
411.00	20.65	412.00	20.69	413.00	20.74	414.00	20.78	415.00	20.83
414.00	20.89	417.00	20.93	417.24	20.94	417.71	20.98	418.00	20.98
415.00	21.04	420.00	21.10	421.00	21.17	422.00	21.24	423.00	21.32
424.00	21.40	425.00	21.45	426.00	21.56	427.00	21.63	428.00	21.69
425.00	21.75	430.00	21.30	430.50	21.62	431.00	21.84	432.00	21.87
433.00	21.88	474.00	21.90	435.00	21.90	476.00	21.90	436.10	21.90
437.00	21.97	453.00	21.90	439.00	21.90	440.00	21.90	441.00	21.90
442.00	21.91	443.00	21.92	444.00	21.92	445.00	21.94	446.00	21.95
447.00	21.95	443.00	21.97	449.00	21.99	450.00	22.00	451.00	22.01
452.00	22.02	453.00	22.03	454.00	22.04	455.00	22.04	456.00	22.04
457.00	22.04	458.00	22.03	459.00	22.02	460.00	22.00	461.00	21.93
462.00	21.95	463.00	21.91	464.00	21.93	465.00	21.94	466.22	21.84
466.00	21.81	467.00	21.76	468.00	21.75	469.10	21.72	469.80	21.70
470.00	21.70	471.00	21.59	472.00	21.55	473.00	21.57	474.00	21.67
475.00	21.69	476.00	21.68	477.00	21.69	478.00	21.65	479.00	21.70
480.00	21.70	481.00	21.70	482.00	21.70	482.10	21.70	482.20	21.69
484.00	21.69	485.00	21.68	486.00	21.68	487.00	21.66	488.00	21.63
489.00	21.67	489.50	21.55	490.00	21.70	491.00	21.72	492.00	21.74
493.00	21.77	494.00	21.30	495.00	21.93	496.00	21.87	497.00	21.90
498.00	21.94	499.00	21.97	499.27	21.95	500.00	22.00	501.00	22.03
502.00	22.05	503.00	22.08	504.00	22.12	507.90	22.40	511.60	23.59
521.10	25.13	525.30	25.59	537.03	25.30	542.80	25.13	550.00	25.10
554.51	24.71	558.60	24.52	562.80	24.02	563.50	23.77	572.30	23.57
580.40	23.19	584.32	23.21	593.60	23.11	593.00	19.65	605.00	18.64
595.85	18.64	610.00	15.64	611.00	18.64	612.00	18.64	613.00	18.64
614.00	18.65	615.00	18.65	616.00	18.66	616.50	18.66	617.00	18.67
616.00	18.67	619.00	18.68	620.00	18.69	621.00	18.69	622.00	18.70
623.00	19.70	624.00	18.71	625.00	18.72	625.20	18.72	626.00	18.73
627.00	18.74	628.00	18.75	629.00	18.77	629.70	18.78	630.00	18.79
631.00	18.81	632.00	18.84	633.00	18.87	634.00	18.90	635.00	18.93

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TABLE A-6 (continued)

λ	σ_I										
636.00	13.97	637.00	19.00	638.00	15.04	639.00	19.08	640.00	19.11		
641.00	19.15	642.00	19.19	643.00	15.22	644.00	19.26	644.10	19.26		
645.00	19.29	646.00	19.33	647.00	19.37	648.00	19.41	649.00	19.45		
650.00	19.52	651.00	19.99	652.00	20.47	653.00	20.96	654.00	21.43		
655.00	21.89	656.00	22.31	657.00	22.70	658.30	22.81	659.00	23.05		
659.00	23.73	660.00	23.55	661.00	23.69	661.40	23.73	662.00	23.75		
663.00	23.78	664.00	23.74	665.00	23.65	666.00	23.53	667.00	23.33		
668.00	23.21	669.00	26.06	670.00	25.37	671.00	28.32	671.50	28.21		
672.00	25.09	673.00	27.85	674.00	22.03	675.00	23.27	676.00	23.25		
677.00	28.40	678.00	22.05	679.00	22.11	680.00	19.53	680.94	19.50		
681.00	19.57	681.70	31.22	682.00	31.21	683.00	31.13	684.00	31.03		
685.00	21.73	685.70	21.62	686.00	21.53	687.00	21.42	688.00	21.26		
689.00	21.10	690.00	18.32	691.00	18.19	692.00	18.06	693.00	35.52		
694.00	35.39	694.30	35.35	695.00	35.23	696.00	35.18	697.00	35.11		
696.00	20.31	699.00	20.33	700.00	20.33	701.00	20.47	702.00	20.58		
703.00	20.71	703.40	20.77	704.00	20.87	705.00	21.04	706.00	21.23		
707.00	21.42	709.00	21.62	709.01	21.83	710.00	21.98	711.00	22.23		
712.00	22.43	712.70	22.36	713.00	22.61	714.00	22.77	715.00	27.71		
716.00	27.81	717.00	27.88	718.00	23.16	718.50	23.16	719.00	23.16		
720.00	23.12	721.00	23.03	722.00	42.35	723.00	42.12	724.00	41.83		
725.00	41.47	726.00	41.05	727.00	40.54	728.00	20.48	729.00	19.77		
730.00	18.56	731.00	18.03	732.00	17.34	733.00	16.01	734.00	20.41		
735.00	5.75	736.00	25.17	737.00	25.99	738.00	30.12	739.00	25.25		
740.00	26.43	741.00	25.73	742.00	24.59	743.00	17.06	744.00	22.76		
745.00	21.51	746.00	20.29	747.00	15.16	748.00	18.30	749.00	16.78		
750.00	16.60	751.00	14.23	752.00	14.55	753.00	10.98	754.00	11.87		
755.00	19.56	756.00	19.72	757.00	19.33	758.00	20.16	758.70	20.28		
759.00	16.49	759.40	16.55	760.00	16.63	760.40	19.31	761.00	15.45		
762.00	15.62	762.00	17.63	763.00	15.73	764.00	12.27	764.60	12.33		
765.00	23.52	766.00	23.67	767.00	23.91	768.00	6.54	769.00	6.59		
770.00	4.61	770.40	6.52	771.00	6.63	772.00	18.35	773.00	18.36		
774.00	19.34	775.00	18.30	776.00	24.58	776.00	31.65	777.00	31.78		
776.00	29.47	779.00	29.19	780.00	15.17	780.30	15.14	781.00	15.03		
782.00	24.83	783.00	24.77	784.00	35.31	785.00	29.28	786.00	35.27		
785.00	9.65	787.00	9.35	787.71	9.35	788.10	9.65	789.00	5.85		
790.00	17.70	790.21	17.70	791.00	18.12	792.00	23.23	793.00	26.59		
794.00	17.04	795.00	7.68	796.00	6.00						

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TABLE A-9

HELIUM PHOTOIONIZATION CROSS SECTIONS σ_I (Mb)

λ	σ_I										
14.25	.05	14.40	.05	15.01	.05	15.26	.05	16.01	.05	16.97	.06
16.77	.05	17.05	.06	17.11	.06	18.62	.06	18.97	.06	19.97	.06
21.60	.07	21.80	.07	22.10	.07	28.47	.08	28.79	.09	30.95	.10
25.52	.09	33.02	.09	30.43	.09	33.74	.10	40.95	.12	46.40	.13
43.70	.12	44.02	.13	44.16	.13	45.66	.13	46.40	.13	50.52	.14
46.67	.13	47.37	.13	49.22	.14	50.36	.14	50.52	.14	54.42	.15
50.65	.14	52.30	.15	52.91	.15	54.15	.15	54.42	.15	56.92	.16
54.70	.15	55.06	.15	55.34	.15	56.08	.16	56.92	.16	59.62	.17
57.36	.16	57.56	.16	57.88	.16	58.96	.16	59.62	.17	61.90	.17
60.30	.17	60.65	.17	61.07	.17	61.63	.17	61.90	.17	63.16	.17
62.30	.17	62.35	.17	62.77	.17	62.92	.17	63.16	.17	64.60	.19
63.30	.17	63.65	.18	63.72	.18	64.11	.18	64.60	.19	67.14	.18
65.21	.18	65.71	.18	65.85	.18	66.30	.18	67.14	.18	70.54	.19
67.35	.19	68.35	.19	69.65	.19	70.00	.19	72.63	.20	74.44	.20
70.75	.19	71.00	.19	71.94	.21	72.31	.20	72.63	.20	75.73	.21
72.80	.20	72.95	.20	73.55	.20	74.21	.20	76.30	.21	77.46	.22
74.85	.20	75.03	.21	75.29	.21	75.46	.21	75.73	.21	79.46	.22
76.01	.21	76.48	.21	76.83	.21	76.94	.21	77.30	.21	80.94	.22
77.74	.21	78.53	.21	78.70	.21	79.09	.22	79.46	.22	82.67	.23
79.76	.22	80.00	.22	80.21	.22	80.35	.22	80.67	.23	84.26	.23
81.10	.22	81.58	.22	81.94	.22	82.43	.22	82.67	.23	85.50	.23
83.25	.23	83.42	.23	83.67	.23	84.30	.23	84.26	.23	86.77	.24
84.50	.23	84.72	.23	84.86	.23	85.16	.23	85.50	.23	88.11	.24
85.69	.23	85.97	.23	86.23	.23	86.40	.23	86.77	.24	89.14	.24
86.50	.24	87.30	.24	87.61	.24	88.10	.24	88.11	.24	90.00	.25
88.14	.24	88.42	.24	88.64	.24	89.90	.24	90.14	.24	92.55	.25
89.70	.24	90.14	.24	90.45	.25	90.71	.25	91.00	.25	94.39	.26
91.46	.25	91.69	.25	91.81	.25	92.39	.25	92.55	.25	95.81	.26
92.81	.25	93.61	.25	94.07	.25	94.25	.26	94.39	.26	95.51	.26
94.31	.24	94.95	.26	95.37	.26	95.51	.26	95.81	.26	96.83	.27
95.50	.25	96.45	.26	96.83	.26	97.12	.26	97.51	.26	98.83	.27
97.27	.25	98.12	.27	98.23	.27	98.50	.27	98.83	.27	100.95	.28
99.44	.27	99.71	.27	99.99	.27	100.54	.28	100.95	.28	103.17	.30
101.57	.29	102.15	.29	103.01	.30	103.15	.30	103.17	.30	105.25	.32
103.56	.31	103.94	.31	104.23	.31	104.76	.32	105.25	.32	108.46	.35
106.25	.33	106.37	.33	106.93	.34	108.05	.35	108.46	.35	110.76	.37
108.50	.34	109.95	.37	110.55	.37	110.52	.37	110.76	.37	114.24	.41
111.16	.39	111.25	.38	113.80	.42	114.09	.41	114.24	.41	120.40	.47
115.39	.42	115.82	.42	116.75	.42	117.20	.44	120.40	.47	127.65	.54
121.15	.43	121.79	.46	122.70	.45	123.50	.50	127.65	.54	136.21	.62
125.97	.55	130.30	.56	131.02	.57	131.21	.57	136.21	.62	144.21	.70
130.20	.62	136.34	.62	136.45	.62	136.46	.62	144.21	.70	152.84	.79
145.00	.71	143.50	.75	150.10	.76	152.15	.72	152.84	.79	159.94	.85
154.20	.87	157.73	.83	158.03	.84	159.94	.85	154.15	.89	168.92	.93
167.50	.90	163.17	.91	168.55	.91	168.92	.91	171.05	.93	175.24	.96
172.12	.93	172.92	.94	173.10	.94	174.53	.95	175.24	.96	180.40	.99
175.47	.95	177.22	.97	176.02	.99	177.74	.95	180.40	.99	183.91	1.003
180.71	1.00	181.14	1.00	182.15	1.01	182.39	1.01	183.91	1.003	186.63	1.006
184.10	1.03	184.52	1.03	184.76	1.04	185.21	1.04	186.63	1.006	189.29	1.011
195.97	1.05	188.48	1.07	188.70	1.08	190.07	1.08	191.29	1.011	196.63	1.019
192.38	1.02	192.50	1.03	193.50	1.04	195.14	1.04	196.63	1.019		

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TABLE A-9 (continued)

λ	σ_I								
197.41	1.20	193.53	1.22	200.00	1.24	201.19	1.26	202.64	1.29
203.70	1.31	204.29	1.34	206.26	1.36	206.38	1.37	207.46	1.39
206.33	1.41	209.63	1.44	205.78	1.44	209.93	1.45	211.32	1.48
212.15	1.50	214.75	1.55	215.16	1.55	216.00	1.59	218.21	1.61
215.05	1.62	220.06	1.63	221.26	1.64	221.51	1.65	223.26	1.66
220.72	1.67	224.31	1.68	225.12	1.68	227.01	1.70	227.47	1.70
226.79	1.72	230.61	1.75	231.55	1.75	232.60	1.78	233.84	1.81
234.75	1.81	235.55	1.83	237.35	1.86	239.37	1.90	240.75	1.92
243.03	1.95	245.94	2.00	246.24	2.01	245.91	2.02	247.16	2.02
249.23	2.05	251.10	2.08	251.96	2.09	252.17	2.10	253.80	2.12
256.37	2.15	256.65	2.17	257.48	2.18	258.40	2.20	259.50	2.22
261.08	2.25	262.55	2.26	264.27	2.27	264.90	2.31	270.50	2.42
271.59	2.44	272.70	2.46	274.24	2.49	275.35	2.51	275.76	2.51
276.15	2.52	276.77	2.53	277.00	2.54	277.27	2.54	278.40	2.56
281.41	2.62	284.15	2.67	285.65	2.71	288.36	2.75	289.17	2.77
290.74	2.80	291.63	2.81	292.00	2.82	292.83	2.84	295.57	2.89
296.17	2.90	299.50	2.96	303.78	2.94	315.72	3.26	315.05	3.26
316.20	3.28	319.83	3.35	335.05	3.67	335.39	3.58	345.13	3.88
345.74	3.89	347.42	3.92	349.85	3.97	353.96	4.03	356.07	4.07
360.76	4.15	364.80	4.22	368.07	4.28	401.70	5.55	405.00	5.87
406.00	5.52	407.00	5.67	408.00	5.62	409.70	6.07	410.00	6.11
411.00	6.15	412.00	6.21	413.00	6.25	414.00	6.25	415.00	6.33
416.00	6.27	417.00	6.41	417.24	6.42	417.71	6.44	418.00	6.45
419.00	6.49	420.00	6.52	421.00	6.53	422.00	6.55	423.00	6.62
424.00	6.65	425.00	6.66	426.00	6.71	427.00	6.74	428.00	6.76
425.00	6.79	430.00	6.81	430.50	6.83	431.00	6.84	432.00	6.85
430.00	6.83	434.00	6.90	435.00	6.92	436.70	6.94	436.10	6.94
457.00	6.95	453.00	6.96	434.00	6.99	440.00	7.01	441.00	7.02
442.00	7.04	443.00	7.05	444.00	7.06	445.00	7.07	446.00	7.09
447.00	7.10	443.00	7.11	449.00	7.12	450.70	7.13	451.00	7.13
452.00	7.14	453.00	7.15	454.00	7.15	455.70	7.16	456.00	7.17
457.00	7.19	453.00	7.18	459.00	7.19	460.00	7.19	461.70	7.20
462.00	7.20	463.00	7.20	464.00	7.21	465.70	7.21	465.22	7.21
466.00	7.22	467.00	7.22	458.00	7.22	469.00	7.22	469.80	7.23
470.00	7.23	471.00	7.23	472.00	7.23	473.70	7.24	474.00	7.24
475.00	7.24	476.00	7.24	477.00	7.25	478.00	7.25	479.00	7.25
480.00	7.25	481.00	7.26	482.00	7.26	482.10	7.26	483.00	7.26
484.00	7.27	483.00	7.27	486.00	7.28	487.00	7.28	488.00	7.29
485.00	7.29	486.50	7.29	480.00	7.30	491.00	7.30	492.00	7.31
487.00	7.31	484.00	7.32	485.00	7.33	496.00	7.34	497.00	7.35
496.00	7.35	499.00	7.36	499.27	7.37	500.70	7.37	501.00	7.39
502.00	7.40	503.00	7.41	504.00	7.42				

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B-1

APPENDIX B

THE DIFFUSIVE TRANSPORT MODEL

The model used for the diffusive transport of atomic oxygen ions is essentially that of Schunk and Walker (1973). There are two relevant equations, the first of which is the equation of continuity

$$\frac{\partial n_j}{\partial t} + \nabla \cdot (n_j \underline{v}_j) = P_j - L_j \quad (B-1)$$

where n_j is the number density of species j , \underline{v}_j is the drift velocity, P_j is the production rate, and L_j is the loss rate. The second relevant equation is the equation of motion. If thermal diffusion, viscosity, and non-linear acceleration terms are neglected, the particle drift velocities may be obtained by solving the equations

$$\nabla P_j - n_j m_j \underline{G} - n_j e_j \underline{E} = n_j m_j \sum_k r_{jk} (\underline{v}_k - \underline{v}_j) \quad (B-2)$$

where $P_j = n_j k T_j$ is the partial pressure for species j , T_j is its temperature, m_j its mass, e_j its charge, \underline{G} is the acceleration due to gravity, \underline{E} is the electric field, k is Boltzmann's constant, and r_{jk} is the momentum transfer collision frequency of species j with species k . Equation (B-2) is valid for both electrons and ions. Using the subscripts i and j to denote ions, n and m to denote neutrals, e to denote electrons, and the convention that a sum over subscript k is over all particles, equation (B-2) takes the following explicit form for electrons:

$$\nabla P_e - n_e m_e \underline{G} - n_e e e \underline{E} = n_e m_e \sum_k r_{ek} (\underline{v}_k - \underline{v}_e) \quad (B-3)$$

B-2

This equation determines the electric field:

$$e \underline{E} = \frac{1}{n_e} \left[-\nabla P_e + n_e m_e \underline{G} + n_e m_e \sum_k r_{ek} (\underline{v}_e - \underline{v}_k) \right] \quad (B-4)$$

where $e \equiv -|e_e|$. The electric field can be eliminated from (B-2) with the help of (B-4). If the neutral atmosphere is assumed stationary, terms of order m_e/m_j are neglected, and ion-ion and ion-electron collision frequencies are neglected (compared to ion-neutral collision frequencies), the equation for a single ion (O^+ in this instance) reduces to

$$\underline{v}_i = -\frac{k T_i}{m_i r_{in}^*} \left[\frac{1}{n_i} \nabla n_i + \frac{1}{T_i} \nabla T_i - \frac{m_i}{k T_i} \underline{G} + \frac{T_e}{n_e T_i} \nabla n_e + \frac{1}{T_i} \nabla T_e \right] \quad (B-5)$$

where $r_{in}^* = \sum_n r_{in}$ is the effective ion-neutral collision frequency. For the vertical component, the equation for the drift velocity becomes

$$v_z = -\frac{1}{n} D \left\{ \frac{dn}{dz} + n \left[\frac{1}{T} \frac{d(T_e + T)}{dz} + \frac{m_e g}{k T} \right] + \frac{n}{n_e} \frac{T_e}{T} \frac{dn_e}{dz} \right\} \quad (B-6)$$

where $D = \frac{kT}{m r^*}$, and the subscripts have been dropped from quantities that refer to the ion. It can be shown that, in the presence of a magnetic field, the diffusion coefficient D is reduced by the factor $\sin^2 I$, where I is the dip angle. If (B-6) is substituted in (B-1), and the time derivative is set to zero, the resulting diffusion equation is one of second order in the ion density n .